

***TRAINING PROGRAMME TO TRAIN THE
TEACHERS IN THE HARD SPOTS IN
TEACHING OF PHYSICS AT HIGHER
SECONDARY STAGE FOR TEACHERS
OF HARYANA, JAMMU & KASHMIR***

PROGRAMME COORDINATOR

DR.S.K.PARADKAR

READER IN PHYSICS

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REGIONAL INSTITUTE OF EDUCATION,
AJMER(RAJ.)305004
(N.C.E.R.T.)

Preface

With the implementation of NCF 2000, new textual materials prepared by NCERT for class XI and XII are in use in several states. The subject matter in the physics text books has been thoroughly revised and upgraded with the inclusion of new unit of principles of communication. Besides the experiments, some short activities have been included. This effort may have caused certain difficulties for the teachers in transacting the content included recently and difficult topics/hard spots in physics at +2 stage. Information and communication technology (ICT) which is the convergence of telecommunications, television and computers has a tremendous potential to revolutionize classroom transaction and transform schools dramatically. It is not only the teaching style that could be influenced by the ICT but also learning style. The effective teacher today not only analyses the concept thoroughly, but also make use of the modern teaching aids to make understanding of the concepts qualitatively better. With the above philosophy in mind a five day training program, to train the physics teachers at +2 stage, was organized at RIE, Ajmer from 3rd to 7th November, 2003. The main objectives of the programme were to

1. Provide content enrichment materials in the topics identified as hard spots by our resource team,
2. Train the teachers in the use of computer multimedia softwares on the selected topics in physics and electronics.
3. Enable to perform the new and difficult activities/experiments recently included in the physics practical at +2 stage.

Dr. S.K. Paradkar and his colleagues did a commendable job to make the programme a success. In my opinion its effect was felt by the participants deeply and they were positively benefited.

Teaching of Science / Physics

Focus of attention

- Structure of thought, previous ideas, historical perspectives ,
- Psychological order of discipline as a contrast to logical order.
- Alternative frameworks and their implications
- Opportunities to test ideas.
- During curriculum transactions:

Encourage	Avoid
➤ Children participation	➤ Lecture
➤ Discussion	➤ Transmission of knowledge
➤ Verbalisation of ideas	➤ Passive learning
➤ Implications of the existing ideas.	➤ Ignorance of students' existing ideas
➤ Testing of ideas / implications	

Methodology for teaching

- a. Adopt **Constructivist approach** of teaching. This could have the following characteristics:
 - Maximise student participation.
 - Let the student state their ideas without inhibition or fear of evaluation.
 - Students are encouraged to discuss and debate pros and cons, implications of various ideas.
 - Pure lectures are reduced to minimum.
 - Students are asked to think aloud, make hypothesis, test them and evaluate their ideas.
- b. Identify learning difficulties and discuss with students, provide additional experiences.
- c. Identify common misconceptions. Design new activities, situations that confront the existing ideas.
- d. Reasons for failing to solve problems need to be explored. These could be,
 - i. Lack of understanding of the problem
 - ii. Lack of knowledge required
 - iii. Existence of alternative frameworks
 - iv. Lack of procedural knowledge.

Teaching of Kinematics

A.B.Saxena

Major concepts : 1. Motion along a straight line

$$\text{Average velocity} = \frac{\Delta s}{\Delta t}$$

$$\text{Instantaneous velocity} = \frac{\Delta s}{\Delta t}$$

[Common misconception velocity $\frac{s}{t}$]

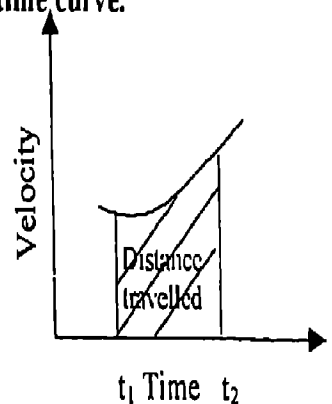
Instantaneous velocity is given by the slope of displacement Time curve

$$\text{Similarly, Instantaneous acceleration} = \frac{\Delta v}{\Delta t}$$

Instantaneous acceleration is given by the slope of velocity – time curve.

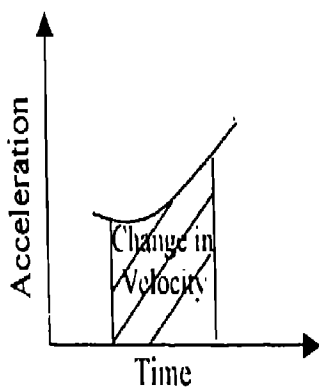
Equations of motion are:

$$v = u + at, \quad s = ut + (1/2) at^2, \quad v^2 = u^2 + 2as$$



Distance traveled by a body is given by the area between velocity – time curve and time axis (see fig.)

Similarly, change in velocity is represented by the area enclosed by acceleration – time curve and time axis (see fig)



2. Motion in a plane

Projectile motion: During projectile motion only force acting on the body is (downward) gravitational force hence only the vertical component of velocity changes **Horizontal component remains unchanged.**

$$\text{Time of flight } T = \frac{2u \sin \theta}{g}$$

$$\text{Maximum height } H = \frac{u^2 \sin^2 \theta}{g}$$

$$\text{Range } R = \frac{u^2 \sin 2\theta}{g}$$

$$\text{Trajectory of projectile } y = \tan \theta \cdot x - \left(\frac{1}{2}\right) \frac{g}{u^2 \cos^2 \theta} \cdot x^2$$

Circular motion [with constant speed and fixed radius]

$$\text{Centripetal force} = \frac{mv^2}{r} = m\omega^2 r$$

Motion in a vertical circle

Equation of motion is:

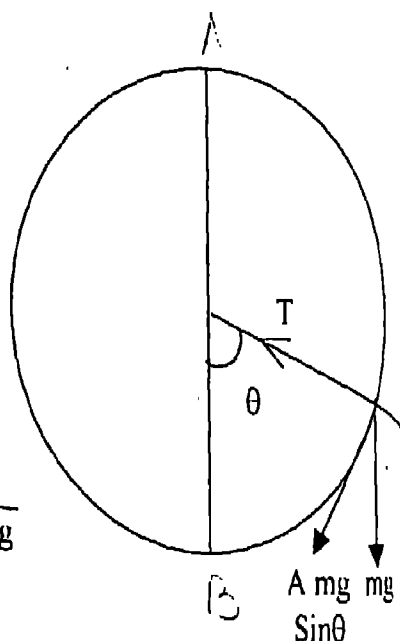
$$\frac{mv^2}{r} = T - mg \cos \theta$$

$$\text{Hence, tension } T = \frac{mv^2}{r} + mg \cos \theta$$

$$\text{At the highest point, } T_{\min} = \frac{mv_B^2}{r} - mg$$

$$\text{At the highest point, } T_{\max} = \frac{mv_A^2}{r} + mg$$

For just completing the circle, the critical speed $v_c = \sqrt{rg}$



3. Vectors: Vectors are those quantity that follow vector algebra. A vector **A** can be represented as,

$$\mathbf{A} = i A_x + j A_y + k A_z$$

Addition of vectors

$$R_x = A_x + B_x + C_x + \dots$$

$$R_y = A_y + B_y + C_y + \dots$$

$$R_z = A_z + B_z + C_z + \dots$$

$$R = \sqrt{R_x^2 + R_y^2 + R_z^2}$$

$$\mathbf{R} = i R_x + j R_y + k R_z$$

$$\cos \alpha = R_x/R, \cos \beta = R_y/R, \cos \gamma = R_z/R$$

Scalar product or dot product

$$\mathbf{a} \cdot \mathbf{b} = |\mathbf{a}||\mathbf{b}| \cos \theta$$

$$= a_x b_x + a_y b_y + a_z b_z; \text{ It has no direction}$$

Vector Product or cross product

$$\mathbf{a} \times \mathbf{b} = |\mathbf{a}||\mathbf{b}| \sin \theta \cdot \hat{n}$$

$$\text{Hence } \mathbf{a} \times \mathbf{a} = 0$$

$$\text{and } i \times j = k, j \times k = i, k \times i = j$$

$$\text{and } \hat{n} = \frac{\mathbf{a} \times \mathbf{b}}{|\mathbf{a}||\mathbf{b}|}. \text{ Vector product has a fixed direction}$$

Example : Work done by a force $\mathbf{F}$, $DW = \mathbf{F} \cdot d\mathbf{s}$

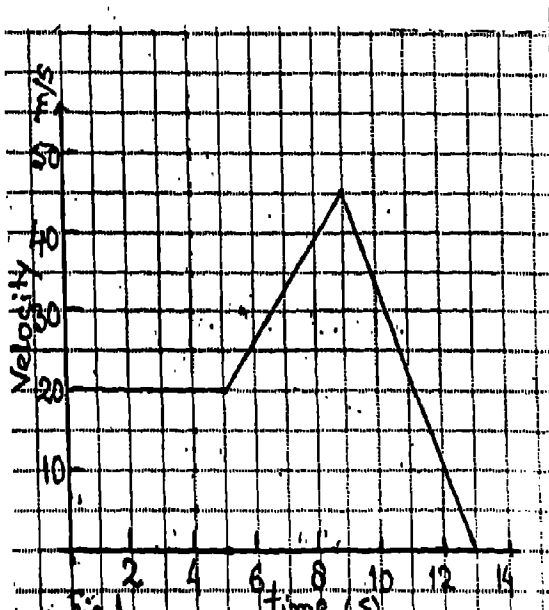
Example : Torque or momentum of a force $\vec{\tau} = \vec{r} \times \vec{F}$

Some common misconceptions

1. Constant Motion Requires a constant force
2. If a body is not moving there is no force acting on it.
3. If a body is moving there is a force acting on it in the direction of motion.
4. A body moves forward as long as 'push' is not dissipated.
5. Acceleration is also zero when velocity is zero
6. On the highest point of trajectory of a projectile, no force is acting.

Think why are they wrong.

Q-1. The graph in Figure.1 shows the velocity of a body plotted as a function of time, (a) Find the instantaneous acceleration at $t = 3\text{s}$, at $t = 7\text{s}$ and at $t = 11\text{s}$ (b) How far does the body go in first 9s?



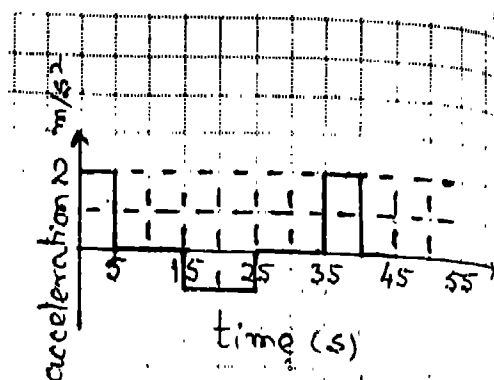
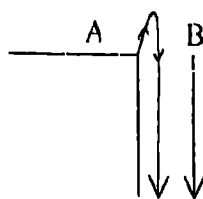


Fig. 2

- Q-2. Figure.2 is a graph of acceleration of a body moving on the x axis. Sketch the graph of its velocity as a function of time if $v = 0$ at $t = 0$.

- Q-3. The reaction time (the time interval between seeing a signal and application of brakes) of an automobile driver is 0.7s. If the automobile can accelerate at 5m/s^2 , compute the total distance, covered is coming to stop from an initial velocity of 30 m/s. after a signal is observed

- Q-4 Two stones A and B are thrown with equal speed from the top of a building. Stone A is thrown vertically upward and B. vertically downward. Which stone would reach to the ground with greater velocity?



- Q-5. A stone is dropped from cornice of a building, takes 0.25s to pass a window 3m high window. How far is the top of the window below the cornice?

- Q-6. What is the angle of projection at which horizontal range and the maximum height of a projectile are equal?

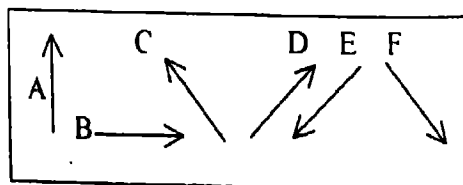
- Q-7. A ball rolls off the edge of a table 1m above the floor, and strikes the floor at a point 1.5m horizontally from the edge of the table. (a) Find the time of flight. (b) Find the initial velocity (c) Find the magnitude and direction of the velocity of the ball just before it strikes the floor.

- Q-8. Find the angle between the two vectors $\vec{A} = 3\hat{i} + 4\hat{j} + 5\hat{k}$ and $\vec{B} = 3\hat{i} + 4\hat{j} - 5\hat{k}$ and value of $\vec{A} \cdot \vec{B}$.

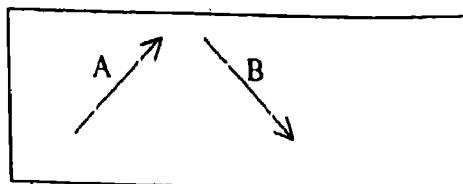
- Q-9. Two constant forces $2\hat{i} + 2\hat{j} + 5\hat{k}$ and $3\hat{i} - 5\hat{j} - 4\hat{k}$ act on a particle which is displaced from the point $2\hat{i} + 4\hat{k}$ to the point $20\hat{i} + 17\hat{j} + 3\hat{k}$. Calculate the work done by the forces.

- Q-10. A particle moves along the curve $x = 2t^2$, $Y = t^2 - 4t$ and $z = 3t - 5$. Find its velocity and acceleration at $t = 5\text{s}$.

- Q-11. Figure shows vectors $\vec{A}$ and $\vec{B}$. Which of the four vectors $\vec{C}$, $\vec{D}$, $\vec{E}$ & $\vec{F}$ has nearly the same direction as vector $\vec{R} = \vec{A} + \vec{B}$?



- Q-12. Figure shows vectors $\vec{A}$ and $\vec{B}$. In the diagrams draw the vector $\vec{R} = \vec{A} - \vec{B}$.



Fundamentals of Electricity

- We do not study “Electricity”, we study electrical science.
- Generators don’t produce “electricity”, they produce “electrical energy” which is made of individual fields resembling radio waves so that they whiz along outside of the wires. A generator also forces the charges of the wires to flow.
- “Electricity” doesn’t flow in wires, “charges” do.
- Batteries don’t supply “electricity”, wires do. A battery is a chemically fueled charge pump. Like any other pump, a battery doesn’t supply the “Stuff” that it pumps. When the battery runs down, it is because its chemical fuel is exhausted, not because any charges have been lost.
- Light bulb doesn’t consume “electricity”. Instead, the charges of the filament are forced to flow fairly fast, and this heats the filament because of a sort of “electrical friction”. Charges flow in, but then they flow back out again and some are used up.
- There are no different types of “electricity”, yet the topic of electrical science is divided into many subtopics such as “charges”, “current”, “imbalanced charge”, “sparks” even “voltages”.
- Avoid saying “static electricity” and “current electricity”. Instead call them “charge imbalance” and “charge flow” or possibly “voltage” and “current”.

What is “Electricity”?

This question is not easy to answer because the word “electricity” has several different meanings. These different meaning contradicts each other, and contradictions confuse everyone. Even teachers, engineers, and scientists have hard time understanding it’s meaning obviously “electricity” cannot be several different things at the same time. Because of the contradictory meanings, we can never pin down the nature of electricity.

Below are the most common meanings of the word “electricity” which one do you think is right?. Think about it carefully if one of these meanings is correct, the other entire thing must be wrong! After all, a “Science term” should never have several conflicting definitions. Unfortunately dictionaries and encyclopedias contain all of these.

- “Electricity” means electric charge.
Examples: Charges of electricity, coulombs of electricity.
- “Electricity” refers to the flowing motion of the electric charges.
Example: Current electricity, Amperes of electricity.
- “Electricity” means Electrical energy
Examples: Price of electricity, kilowatt-hours of electricity, electricity bill.
- “Electricity” refers to the amount of imbalance between quantities of electrons and protons.
Example: Static Electricity
- “Electricity” is a class of phenomena involving electric charges.
Examples: Bioelectricity, Piezoelectricity, Triboelectricity, thermoelectricity, Atmospheric electricity

Other less common definitions

- “Electricity” refers to the “Flowing motion of electric energy (electric power, watts of electricity)
- “Electricity” means “Electric field” (volts of electricity)
- “Electricity” means the nitrogen/oxygen plasma (spark of electricity) atmospheric electricity

- “Electricity” is a field of Science (Basic Electricity Advanced Electricity)

If we wish to agree on a single correct definition of “Electricity”, which definition should we choose?

“Electricity is a mysterious, incomprehensible entity which is invisible and visible at the same time. It is both matter and energy. It is a type of low frequency radio waves which is made of protons. It is a mysterious force which looks like blue white fire and yet cannot be seen. It moves forward at the speed of light, yet it vibrates in the AC chord without flowing forwards. It’s totally weightless, yet it has a small weight. When electricity flows through the light bulb’s filament, it gets changed entirely into light and heat energies. Yet no electricity ever used up by the light bulb, and every bit of it is flows out of the filament and back down the other wire.

Electricity:-

This word names a branch or subdivision of physics, just as other subdivisions are named “Mechanics” “Thermodynamics” “Optics”, etc.

Misuse alert: Sometimes the word electricity is colloquially misused as if it named a physical quantity, such as “The capacitor stores electricity”, or “Electricity in a resistor produces heat.” Such usage should be avoided. In all such cases there is a more specific or precise word available such as “The capacitor stores electrical energy”. The resistor is heated by the electric current and “The utility company like RSEB, DESU, BEST etc. charges me for the electrical energy I use. Instead, of electricity as physical entity.

Current:- The time rate at which charge passes through a circuit element or through a fixed place in a conductor wire, $I = dq/dt$

Misuse alert:- A very common mistake found in text books is to speak of “flow of current”, current itself is the flow of charge: what, then, could “flow of current” means? It is redundant, misleading or wrong.

Whenever electric charge moves or flow that is an electric current. The word “electric current” are the same as the words “charge flow”.

An Analogy:- If charge is like air then electric current is like wind, or if charge is like water than electric current is like “gallons per second” of water flow. More precisely the rate at which charges flow.

What is voltage?

“Voltage” or “electric potential” is one way that we can measure an electric field. To produce a very high voltage, rub a balloon on your dry hand or scuff your shoes upon floor when the humidity is very low.

Electric field can push or pull upon electric charges, so electric forces are caused by voltages. In a battery circuit, the voltage from the battery causes the charges of the wire to flow. Voltages caused current? Some people like to say that voltage is a sort of “electric pressure”.

That’s almost correct (It’s correct as far as grade school is concerned, but in physics classes we will learn that voltage is not pressure, not exactly)

From the physicist’s point of view, potential difference refers to the inequality of charges between the battery terminals. This inequality of charges results from chemical reactions inside the battery (The separation of positive and negative charges and their accumulation on opposite sides)

Potential difference is the origin of electric current, that is, it is the origin of the motion of the free electrons in conductor to replace missing electrons at positive battery terminal. Potential difference, resulting from electrochemical reaction inside the battery, has a constant value.

Potential or potential difference?

Potential difference depends on two points :- Specifically, it is the energy per unit charge involved in moving between those points. Always think of potential difference in terms of two points. This is ultimately a very practical matter, if you forget it, you would be able to hook up a voltmeter properly, or connect jumper cable safely to your car battery!

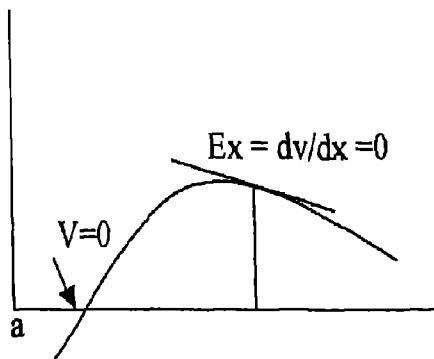
Sometimes we speak of “the potential at a point P”. This is always a shorthand way of talking, and we must have in mind some other point what we mean is the potential difference going from that other point to point P.

Typical potential differences

Between human arms & leg due to heart’s electrical activity	1mv
Across biological cell membrane	80mv
Between terminals of flash light battery	1.5V
Car battery	12V

Across loud speaker operating at 50 watts	20V
Electrical out – let U.S	120V
Electrical out-let Europe, India	230V
Between accelerating electrodes on TV picture tube	30KV
Between long distance electric transmission lines & ground	365KV
Between base of thunderstorm cloud & ground	100MV

Field and potential are not proportional. In particular, where one is zero, the other need not be zero. You can see in Fig (2) where it clearly taken works to set-form infinity to the point where $E=0$. Just because a mountain top is flat doesn't mean it didn't take work to climb up. Potential depends not on the field at a point but on the field over an entire path from infinity to that point. Similarly, the potential can be zero at points where the field is not, as evidence by the steep slope of potential curve in fig.



What is Electric Power?

“Electric power” means “flow rate of electrical energy”. If electric energy were like water, then electric power would be the gallons per second. Energy is measured in Joules, and when energy flows, the flow is measured in Joules per second. What is watt? The word ‘watt’ is just another way of saying Joules per second.

The important part: energy is like stuff, but power is not stuff. Power is a Flow Rate of energy, or a rate of use of energy. We can store electric energy, but electric power is something that is ever stored (Think in this way: we can store gallons of water, but it's impossible to store any “gallons per second” of water).

What is electrical Energy?

Each of these is a kind of electrical energy:

X-ray, Light, Microwaves, Radio signals, Telephone signals. These five things are exactly the same, only their frequency is different. Power lines carry the

same “Stuff”, but the frequency is even lower, it is 60 Hz / 50 Hz (Hz means cycles per seconds), And batteries produce the same “Stuff”, direct current (dc), but the frequency is zero. Let us add them to the above list:

- X-ray
- Light
- Microwaves
- Radio Signals
- Telephone Signals
- Energy from electric companies
- Energy from batteries: - all primary, secondary cell, Lechlanché, Daniell standard cell, Dry cell, Rechargeable cells. etc.

Electrical energy is also called “ Electromagnetic energy” or “electromagnetic vibrations”. Electrical energy is a type of wave energy – waves always moves very quickly (they usually move at the speed of light) when you switch on light bulbs, it light up instantly because the electrical energy moves so fast.

Electrical energy is a combination of two things:

Magnetic fields and electrostatic fields, Electrical energy can be guided or sent from one place to other on transmission lines, it can also travels through space without any wires.

There is no basic different between ‘radio signals’ and ‘AC power”, only their frequency is different.

Capacity and Capacitance:- This word is properly used in names of quantities which express the relative amount of same quantity with respect to another quantity upon which it depends. For example heat capacity is dU/dT , where U is the internal energy and T is the temperature. Electrical capacity, usually called Capacitance is another example: $C = dQ/dV$, where Q is the magnitude of charge on each capacitor plate and V is the potential difference between the plates.

Capacitance:- The capacitance of a capacitor is σ measured by this procedure: Put equal and opposite charges on its plates and then measure the potential difference between the plates. Then $C = Q/V$, where Q is the charge on one of the plates.

Capacitors for use in circuits consist of two conductors (plates). We speak a capacitor as "charged" when it has charge Q on one plate, and $-Q$ on the other. Of course the net charge of the entire object is zero; that is the charged capacitor hasn't had net charge added to it, but has undergone an internal separation of charge. Unfortunately this process is usually called Charging the capacitor, which is misleading because it suggests adding charge to the capacitor. In fact, this process usually consists of moving charge from one plate to the other. The capacitance of a single object, say an isolated sphere, is determined by considering the other plate to be an infinite sphere surrounding it.

The object is given charge by moving charge from the infinite sphere, when acts an infinite charge reservoir (ground). The potential of the object is the potential between the object and the infinite sphere.

Capacitance depends only on the geometry of the capacitors physical structure and the dielectric constant of the material medium in which the capacitor's electric field exists. The size of the capacitors capacitance is the same whatever the charge and potential (assuming the dielectric constant doesn't change)

This is true even if the charge on both & plates is reduced to zero, and therefore the capacitor potential is zero. If a capacitor with charge on its plates has a capacitance of, say, 2 microfarad ($2\mu\text{fd}$), then its capacitance is also 2 microfarad when the plates have no charge. The showed remind us that $C = Q/V$ is not by itself the definition of capacitance, but merely a formula which allows us to relate the capacitance to the charge and potential when the capacitor places have equal and opposite charge on them.

A common misunderstanding about electrical capacitance is to assume that capacitance represents the maximum amount of charge a capacitor can store.

That is misleading because the capacitors don't store charge (their total charge being zero) but their plates have equal and opposite charge. It is wrong because the maximum charge one may put on a capacitor plate is determined by the potential at which dielectric breakdown occurs.

We probably should avoid the phrase "Charged Capacitor" or "charging a capacitor" instead use energizing a capacitor because the process is one of giving the capacitor electrical potential energy by rearranging charges in it.

What is an imbalance of charge?

Objects are matter and matter is made of a combination of positive and negative electric charge. When quantities of positive and negative electric charge are not perfectly equal, there is an imbalance of charge. An imbalance of charge is commonly called "Static Electricity", but this is misleading because there is nothing "Static" about it".

What is spark?

A spark is a volume of air, which has been electrically converted from a gas into plasma, the fourth state of matter. While plasma can be created by high temperatures, it can also be created electrically. Sparks are made of glowing air, and the colour of the spark depends on the type of gases involved. Sparks in nitrogen / oxygen are bluish-violet, white spark in neon are red/orange.

Sparks are conductive, and they can contain an electric current in much the same way that a wire can.

What is a Charge?

Everybody reanalyzes that electricity has an important place in modern way of living. You cannot do anything without the electrical energy. Before discussing its effects let us first clear yourself what do you actually mean by the term electricity? What is electric charge?. How to define the term charge?. There are many misconceptions about electricity. Let us start with the term 'charge'. What is electric charge?. There are many ways to describe the charge.

Charge is

- ... the stuff that flows during an electric current.
- ... the stuff that appears on a balloon when you rub it on your dry hair.
- ... The stuff that comes in two kinds positive and negative.
- ... The plus and minus electric poles (as opposed to North and South magnetic poles)
- ... The stuff that causes electrical forces.
- ... The 'glue' that connects all the flux-lines of electrostatic fields to protons and electrons.
- ... The positive and negative stuff that forms atoms
- ... The stuff that is carried by electrons, protons, positrons, and other particles.
- ... The medium that energy flows through / like sound flows through air)
- ... The stuff that, when it wiggles fast, creates light.
- ... The stuff that when it wiggles slower, creates radio waves.
- ... The stuff that when it wiggles very slowly, creates energy in electric circuits.
- ... The stuff that when it flows or spins, creates magnetism.
- ... The stuff that reflects light and makes objects visible.
- ... The stuff that makes metals look silvery.
- ... The stuff that causes electrical attraction & holds everyday objects together.
- ... The stuff inside of wires that is movable, almost fluid.
- ... The stuff inside of non-conductors that is immobile and frozen' in place.
- ... The stuff that measurement in units called coulomb.
- ... The stuff that scientist once called " quantity of electricity" and "particles of electricity"

If we look up "electric Charge" in a dictionary., we encounter a problem. The definition of "charge" is circular. What is charge?. It's the stuff that causes

electrical phenomena. What are electrical phenomena? Those are the things caused by charge! Simple, no?. There is a good reason why the definition of "charge" is circular. Like mass, length and time, electric charge is a "fundamental". Many dictionaries say this "electric charge: a fundamental property of matter". The word "charge is used to define other things, and therefore the definition of the word "charge becomes a serious problems! What is an electric current?. It is a flow of charge. What is electric charge? It is the stuff that flows during an electric current!. The circular definition is hard to avoid because normal definitions are based upon deeper concepts, and when we finally arrive at the deepest concepts of all, we cannot "take them apart" into their fundamental prices.

What is charge?. What is mass?. What is time?. This is asking what is 'WHAT'? or 'what' is Is'? Very hard to answer. Yet there is a way to do it. Look at the context in which we use word.

Electric charge is a component of atoms. In other words, after we have broken an object into molecules, and broken molecules into atoms, when we break atoms apart we discover particles of electric charge. Charge is material, it like atoms but it is one step lower than atoms. Most science text books tells us that solid objects are made of atoms. It is also valid to state that solid objects are made up of electric charge. Objects are made of equal quantities of positive and negative charge, and objects stay together because of attraction between quantities of opposite charge inside them. Chemical bonds are electrical in nature. Atom as a whole is a neutral entity. It means it has equal number of opposite charges.

Every material is composed of charges and when these charges are made to move we call it "physical motion". Since matter is composed of charge - carrying particles, all physical motion is a motion of charge, but it most cases both the negative and the positive charges move along as one. When opposite charges moving along together are "mechanical", while opposite charges moving differently are "electrical" . If the negative charge in an object should start moving while an objects positive charge stays at rest, then we call that motion an electric current. The words "electric current" mean the same as "charge flow"?

Charge: it's not energy-

Charge is not energy. A quantity of charge can have many different amounts of energy, and if you know the amount of charge, you have no knowledge of the amount of energy present. Charge and energy moves differently; in AC cables

the charges sit in one spot and slowly wiggle, while the energy flows along at almost the speed of light. (Charge is as different from electrical energy as air is different from sound waves!) charge in a circuit flows slowly in a circle like a drive belt, while energy moves quickly from the source to load. If we calculate the drift velocity of electron it is equal to ≈ 6 mm/sec while electrical energy transmitted at the speed of light?

Charge is “Poles”? The charges exist in two polarities positive and the negative. When the positive and the negative charges of matter are sorted out and pulled away from each other “Static electricity” is the result. When (+) is pulled away from (-), an invisible force field connects them and causes them to attract each other. This field is a similar to magnetism in many ways, but it is not magnetism, it is called an “Electrostatic field” or ‘e- field’. Magnetism is a result when these charges moves relative to each other in a conductor with some velocity. We can say that electric charge is the “glue” which attaches the flux lines of e-field to the particles of matter.

Charges are not invisible?

Here is a way to see charge directly; look at the surface of a wire, Metals looks metallic because they contain a “fluid” composed of movable electrons. This electrical fluid is an excellent reflector of metals to act like ‘reflectors of light waves, and it causes the surfaces of metals to act like mirrors. It is the same electrons which flows during an electric current. The “Silvery stuff” of a metal is a charge. What is charge? It is a “silver liquid” which is found in all metals, and which can be forced to flow. Even though the charge is visible in the form of metallic luster, its flow is not look carefully at wire in an operating electric circuit and you won’t see anything moving along. This is not mysterious stir a glass of water then look for the flowing motion. You’ll see moving bubbles & perhaps moving specks of dirt, but you won’t see the water move. The silvery charge fluid in a wire has no bubbles or dirt, so even though the charges visible, we cannot tell if it moving or still.

ELECTROMAGNETIC INDUCTION ALTERNATING CURRENT AND ELECTROMAGNETIC WAVES

Dr. Shashi Prabha
RHE, Ajmer

Electromagnetic Induction

When a conductor is moved through a magnetic field, a voltage is induced across the conductor. This principle is known as electromagnetic induction and the resulting voltage is an induced voltage.

Faradays' Law

He found that moving a magnet through a coil of wire induced voltage across the coil and that when a complete path was provided, the induced voltage caused an induced current. His two observations are stated below-

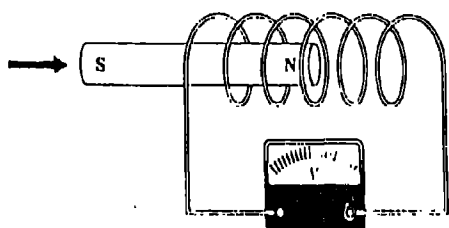
- The amount of voltage induced in a coil is directly proportional to the rate of change of the magnetic field with respect of the coil.
- The amount of voltage induced in a coil is directly proportional to the number of turn of wire in the coil.

Mathematically, the induced emf is $E = -N \frac{d\phi_B}{dt}$

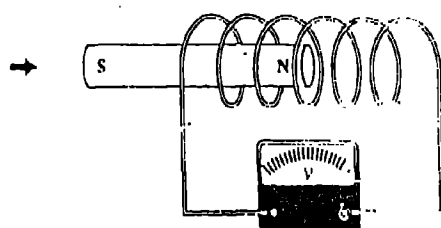
where $\phi_B = B.A. = BA \cos\theta$, A is area of the coil

N is no. of turns in the coil.

and minus sign indicates that the induced emf tends to oppose the flux change.



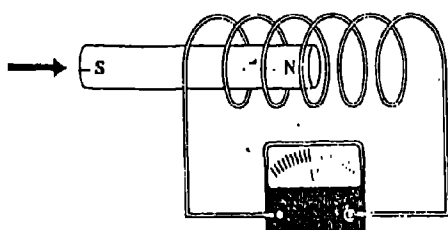
(a) As magnet moves slowly to the right, magnetic field is changing with respect to coil, and a voltage is induced.



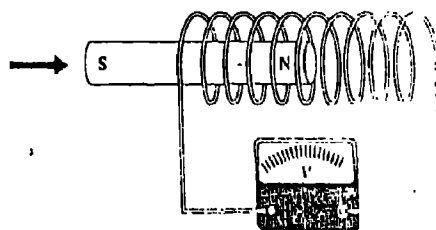
(b) As magnet moves more rapidly to the right, magnetic field is changing more rapidly with respect to coil, and a greater voltage is induced.

FIGURE 1

A demonstration of Faraday's first observation: The amount of induced voltage is directly proportional to the rate of change of the magnetic field with respect to the coil.



(a) Magnet moves through a coil and induces a voltage



(b) Magnet moves at same rate through a coil with more turns (loops) and induces a greater voltage

FIGURE 2

Thus the magnetic flux through a coil can be changed by following way :

- 1 Change the magnitude B of the magnetic field within the coil.
- 2 Change the area of the coil, or the portion of that area that happens to lie within the magnetic field (for example, by expanding the coil or sliding it in or out of the field).
- 3 Change the angle between the direction of the magnetic field B and the area of the coil A .

How voltage is induced in a conductor in a magnetic field

When a wire is moved across a magnetic field, there is a relative motion between the wire and the magnetic field. Likewise, when a magnetic field is moved past a stationary wire, there is also relative motion. In either case, this relative motion results in an induced voltage (V_{ind}) in the wire, as shown by fig. 3 (a) and 3(b).

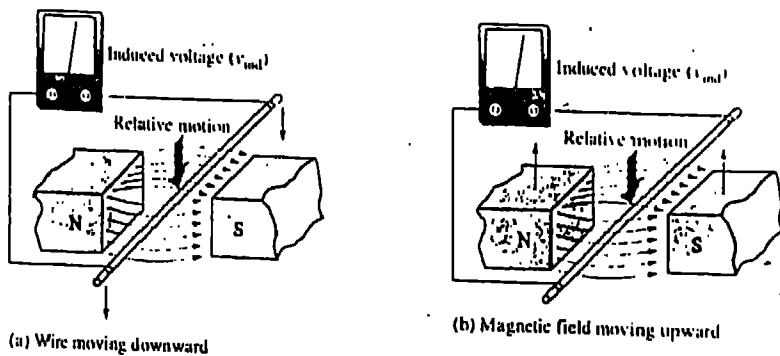


FIGURE 3
Relative motion between a wire and a magnetic field.

If the conductor in figure 3(a) and 3(b) is moved first one way (say downward) and then another (say upward) in the magnetic field, a reversal of the POLARITY of the induced, voltage will be observed as shown in fig 4(a) and 4(b).

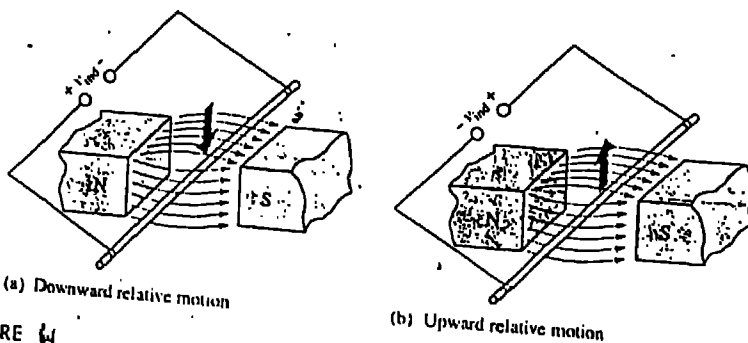
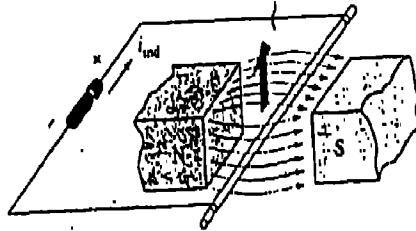


FIGURE 4
Polarity of induced voltage depends on direction of motion.

When a load resistor is connected to the wire in the above figure, the voltage induced by the relative motion in the magnetic field will cause a current in load as shown in fig.5. This current is called the induced current.

FIGURE 5:
Induced current (i_{ind}) in a load as the wire moves through the magnetic field.



The action of producing a voltage and a current in a load by moving a conductor across the magnetic field is the basis for electrical generator.

Lenz Law

It states that 'the polarity of the induced emf is such that it tends to produce a current with opposes the change that produces it.' To clarify it let us apply it in two different but equivalent way to fig.6. Where the north pole of the magnet is being moved towards a conducting loop.

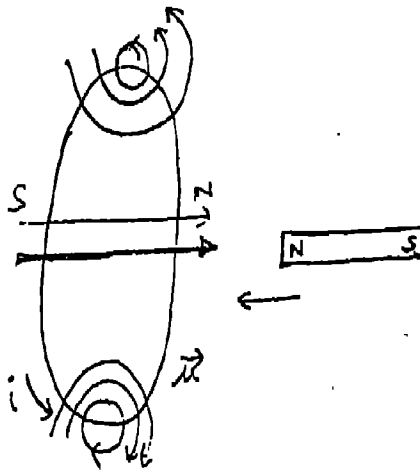


Fig.6. Lenz law at work. As the magnet is moved towards the loop, a current is induced in the loop. The current produces its own magnetic field, with magnetic dipole moment is μ oriented so as to oppose the motion of the magnet. Thus the induced current is anticlockwise.

1.Opposition to Pole movement

The approach of the magnet's north pole in fig.6. increases the magnetic flux in the loop and thereby induces a current in the loop.

The loop then acts as a magnetic dipole with its magnetic dipole moment directed from south to north. To oppose the magnetic flux increase being caused by the approaching magnet, the loop's north pole must face towards the approaching north pole so as to repel it. Then the curled straight right hand rule for it tells that the current induced in the loop must be anticlockwise.

If we next pull the magnet away from the loop a current will again be induced in the loop. Now the loop will have a south pole facing the retreating north pole of the magnet, so as to oppose the retreat. Thus the induced current will be clockwise.

2. Opposition to Flux change –

In Fig. 6, with the magnet initially distant, no magnetic flux passes through the loop. As the north pole of the magnet then nears the loop with its magnetic field $\vec{B}$ directed towards the left the flux through the loop increases. To oppose this increase in flux, the induced current i must set up its own field $\vec{B}_i$ directed towards the right inside the loop as shown in fig. 7(a), then the rightward flux of field $\vec{B}_i$ opposes the increasing leftward flux of the field $\vec{B}$. The curled straight right hand rule then tells us that i must be anticlockwise in fig. 7(a).

Flux of $\vec{B}_i$ always opposes the change in the flux of $\vec{B}$, but that does not always mean that $\vec{B}_i$ points opposite to $\vec{B}$. For example, if we next pull the magnet away from the loop, the flux ϕ_B from the magnet

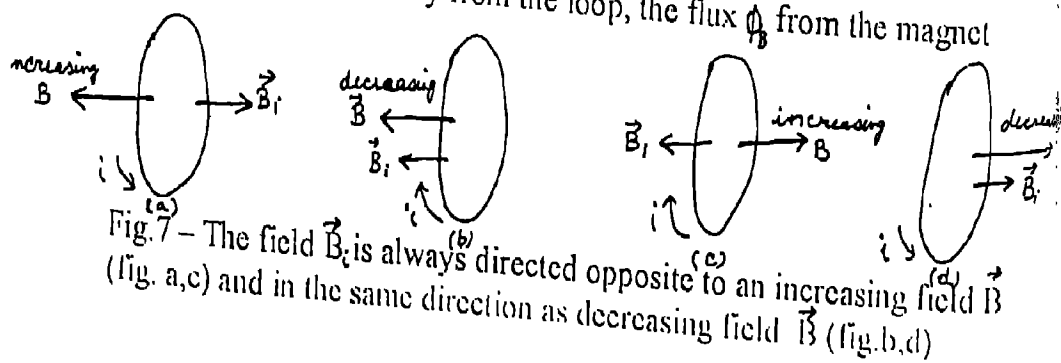


Fig. 7 – The field $\vec{B}_i$ is always directed opposite to an increasing field $\vec{B}$ (fig. a,c) and in the same direction as decreasing field $\vec{B}$ (fig. b,d)

is still directed to the left through the loop, but it is now decreasing. The flux of $\vec{B}_i$ must now be to the left inside the loop to oppose the decrease in Φ_B as shown in fig.7(b). Thus $\vec{B}_i$ and $\vec{B}$ are now in the same direction. Fig. 7(c) and 7(d) show the situations in which the south pole of the magnet approaches and retreats from the loop, respectively.

A.C. Generator

Fig.8 shows how a sine wave voltage is produced by the basic a.c. generator as the loop rotates. An oscilloscope is used to display the voltage waveform.

To begin, fig.8(a) shows the loop rotating through the first quarter of a revolution. It goes from an instantaneous horizontal position, where the induced voltage is zero to an instantaneous vertical position, where the induced voltage is maximum. At the horizontal position the loop is instantaneously moving parallel with the flux lines, thus no lines are being cut and the voltage is zero.

As the loop rotates through the first quarter cycle, it cuts through the flux lines at an increasing rate until it is instantaneously moving perpendicular to the flux lines at the vertical position and cutting through them at a maximum rate. Thus the induced voltage increases from zero to a peak during the quarter cycle. This part of the rotation produces the first quarter of the sine wave cycle as the voltage builds up from zero to its positive maximum

When the loop completes the first half of a revolution, the voltage decreases from its positive maximum back to zero, as shown in fig.8b

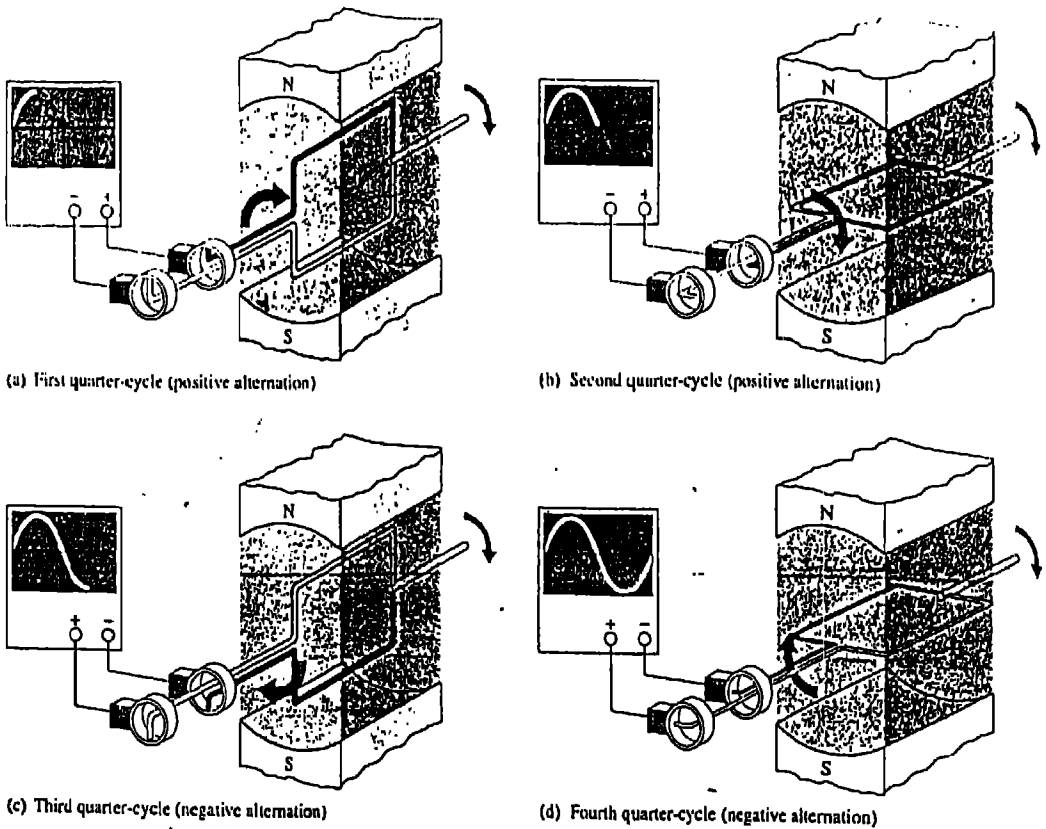


FIGURE 8 :

Fig.8 One revolution of the loop, generates one cycle of the sine wave voltage.

During the second half of the revolution, illustrated in fig. 8(c) and 8(d) the loop is cutting through the magnetic field in the opposite direction, so the voltage produced has a polarity opposite to that produced during first half of the revolution. After one complete revolution of the loop, one full cycle of the sine wave voltage has been produced. As the loop continues to rotate, repetitive cycles of the sine wave are generated.

POWER IN AC CIRCUIT

In a purely resistive AC circuit, all of the energy delivered by the source is dissipated in the form of heat by the resistance. In a purely inductive A.C. circuit, all of the energy delivered by the source is stored by the inductor in its magnetic field during a portion of the voltage cycle and then returned to the source during another portion of the cycle so that there is no net energy conversion to heat. Similarly in a purely capacitive A.C. circuit, all of the energy delivered by the source is stored by the capacitor in its electric field during a portion of

voltage cycle and then returned to the source during another portion of the cycle. When there is both resistance and inductance or capacitance, some of the energy is alternatively stored and returned by the inductance or capacitance and some is dissipated by the resistance. The amount of energy converted to heat is determined by relative values of the resistance and induction or capacitive reactance.

The formula for power in a resistor is called true power them (unit :watt) and the power in the capacitor or in the inductor is called reactive power P_r (unit is volt ampere reactive VAR).

$$P_{true} = I^2_{total} R$$

$$P_r = I^2_{total} X_c$$

$$P_r = I^2_{total} X_L$$

The Power Triangle :

The generalised impedance phasor diagram for R.C.circuit is shown in fig.1(a) A phasor relationship for power can also be represented by a similar diagram because the respective magnitude of the powers, P_{true} and P_r differ from R and X_c by a factor of I^2_{total} told as shown in fig.(b)

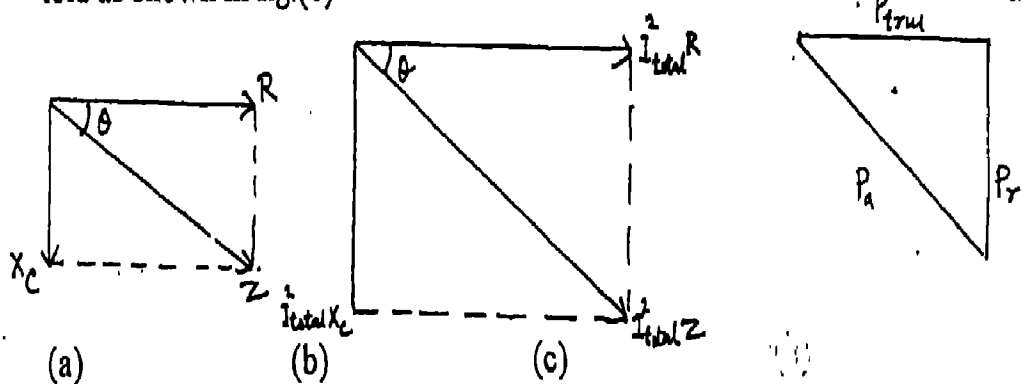


Fig.1 – Development of power triangle for an R.C. circuit

The resultant power phosor represents the apparent power P_a , at any instant of time. P_a is the total power that appears to be transferred between the source and the R-C or L-C, circuit. Part of the apparent power is true

power is true power and part of it is reactive power. The unit of apparent power is the volt ampere.

$$P_a = I^2(\text{total}) Z^2$$

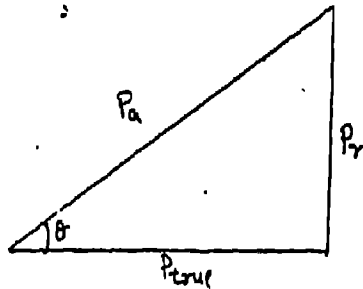


Fig.2 – Generalised power triangle for R.L.circuit

The power phasor diagram in fig.1(b) can be rearranged in the form of a right triangle as shown in fig. 1(c), which is called the power triangle. Using the rules of trigonometry, P_{true} can be expressed as

$$P_{true} = P_a \cos \theta = V_s I(\text{total}) \cos \theta$$

V_s is applied voltage, I_{total} is total current and $\cos \theta$ is called power factor. It can vary from 0 for a purely reactive circuit to 1 for a purely resistive circuit or at resonance in an LCR circuit.

For the case of purely resistive circuit $\theta = 0^\circ \therefore \cos \theta = 1$

so P_{true} equals $V_s I(\text{total})$

For purely capacitive or inductive circuit $\theta = 90^\circ$, $\cos 90^\circ = 0$

so P_{true} is zero. In an LCR circuit power dissipated is $\theta = \tan^{-1} \frac{X_C - X_L}{R}$

Skin effect

The inductance of any circuit through which an alternating current is flowing results in induced emf opposing the applied emf and hence reduces the magnitude of the current

When dealing with high frequency currents in which the current is fluctuating very rapidly, the inductance of even a straight solid conductor, even with no neighbouring conductor must be taken into account. As the magnetic field due to current in such a conductor is within the conductor as well as around it, a change in current produces

a greater change in flux across the inner core than across the outer layers. As a result, the induced emf opposing the applied p.d is greater, and the effective resistance or impedance is higher at the centre than in the outer layer. As a result, current is no longer distributed uniformly through any cross section but is concentrated in the outer layers. This is known as skin effect. It indicates that only the outer layers of a wire, other than one of extremely small diameter provide a conducting path for a very high frequency alternating current.

L-C oscillations

In L-C circuit the charge, current and potential difference do not decay exponentially with time but vary sinusoidally with period T and angular frequency. The resulting oscillations of the capacitor's electric field and the inductive magnetic field are said to be electromagnetic oscillation. Such a circuit is said to oscillate.

The energy stored in the electric field of the capacitor at any time is $U_E = \frac{q^2}{2C}$
 " " " " " magnetic field of the inductor " " " " " $U_B = \frac{1}{2} Li^2$
 q is charge in the capacitor at that time and
 i is current through the inductor at that time.

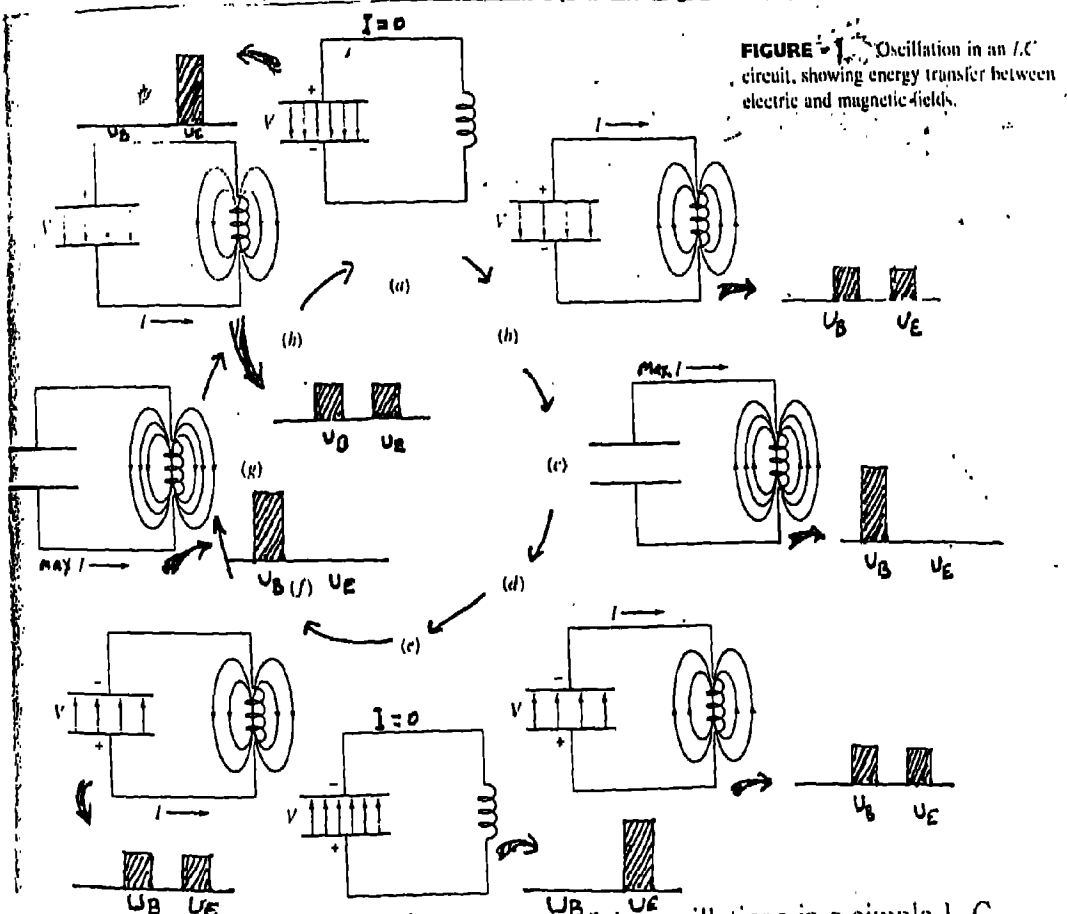


Fig. 1(a-h) show succeeding stages of the oscillations in a simple L-C circuit.

Let us assume that initially the charge q on the capacitor in the figure 1(a) is at its maximum value Q and the current i through the inductor is zero. The bar graph for energy indicates that at this instant with zero current through the inductor and maximum charge on the capacitor, the energy U_B of the magnetic field is zero and the energy U_E of the electric field is a maximum.

Fig. 1(a-h) show eight stages in a single cycle of oscillation of a resistanceless L-C circuit. The bar graphs by each figure show the stored magnetic and electric energy.

- a) Capacitor with max charge, no current
- b) Capacitor discharging, current increasing
- c) Capacitor fully discharged, current max
- d) Capacitor charging but with polarity opposite that in (a), current decreasing
- e) Capacitor with maximum charge having polarity opposite that in (a), no current
- f) Current discharging current increasing with direction opposite that in (b)
- g) Capacitor fully discharged, current maximum
- h) Capacitor charging current decreasing.

The capacitor now starts to discharge through the inductor, positive charge carriers moving anti clockwise as shown in fig. 1(b) This means that a current i given by dq/dt and pointing down in the inductor is established. As the capacitor's charge decreases, the energy stored in the electric field within the capacitor also decreases. This energy is transferred to the magnetic field that appears around the inductor because of the current i and that is building up there. Thus, the electric field

decreases and the magnetic field builds up as energy is transferred from the electric field to the magnetic field.

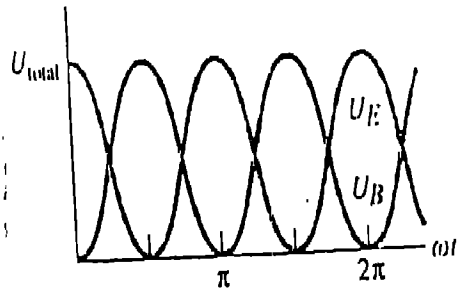


FIGURE - 2. Electric and magnetic energies in an LC circuit. Their sum is constant.

The capacitor eventually loses all its charge (fig.1 c) and thus also loses its electric field and the energy stored in that field. The energy has then been fully transferred to the magnetic field of the inductor. The magnetic field is then at its maximum magnitude, and the current through the inductor is then at its maximum value I .

Although the charge on the capacitor is now zero, the anticlockwise current must continue because the inductor does not allow it to change suddenly to zero. The current continues to transfer positive charge from the top plate to the bottom plate through the circuit, fig.1(d). Energy now flows from the inductor back to the capacitor as the electric field within the capacitor builds up again. The current gradually decreases during this energy transfer. When the energy has been transferred completely back to the capacitor fig.1(e) the current has decreased to zero momentarily. The situation of fig.1(e) is like the initial situation except that the capacitor is now charged oppositely.

The capacitor then starts to discharge again, but now with a clockwise current fig.1(f) Reasoning as before, we find that the clockwise current builds to a maximum, fig 1(g) and then decreases fig.1(h) until the circuit eventually returns to its initial situation fig.1(a)

The process then repeats at some frequency f and thus angular frequency is $\omega = 2\pi f$. In the ideal LC circuit with no resistance, there is no energy transfers other than that between the electric field of the capacitor and the magnetic field of the inductor. But in actual L-C circuit the oscillations will not continue indefinitely because there is always some resistance present. The oscillation once started will die away with time.

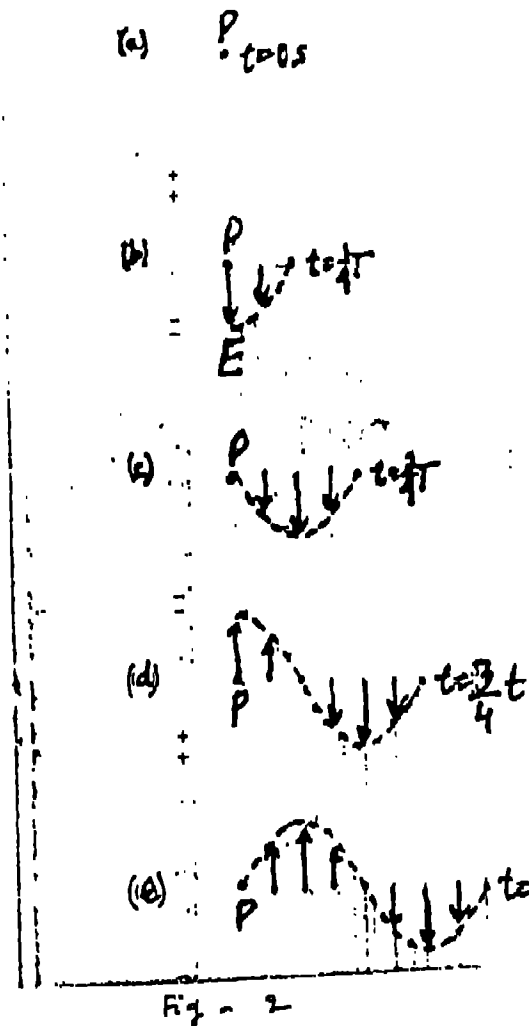
Producing electromagnetic wave

An electromagnetic wave is a transverse wave because the electric and magnetic fields are both perpendicular to the direction in which the wave travels. These waves can travel through vacuum or a material substance since electric and magnetic fields can exist in either case. E.M. waves can be produced in situation that do not involve a wire antenna. In general, any electric charge that is accelerating emits an electromagnetic wave, whether the charge is inside a wire or not. In an alternating current, an electron oscillates in simple harmonic motion along with the length of the wire and is one example of an accelerated charge.

Accelerated charge is the source of electromagnetic wave

Fig. 1 illustrates one way to create an electromagnetic wave. The set up consists of two straight metal wires that are connected to the terminals of an AC voltage source and serve as an antenna. The

potential difference between accelerated charges are electrons moving back and forth in the antenna, driven by an alternating voltage from an LC circuit. Oscillation of L.C. circuit drive alternating current in the antenna, while a power source replenishes the energy carried away in electromagnetic waves.



The terminals changes sinusoidally with time t and has a period T . Part (a) if fig (2) shows the instant $t=0$ sec, when there is no charge at the ends of either wire. Since there is no charge, there is no electric field at the point P just to the right of the antenna. As time passes. The top wire becomes positively charged and the bottom wire negatively charged. One quarter of a cycle later ($t=T/4$), the charges have attained their maximum values, as part b of the fig. indicates. The corresponding electric field E at point P has increased to its maximum

strength in the downward direction. Part b also shows that the electric field created at earlier times has not disappeared but has moved to the right. Only the field moving to the right is shown in the picture for the sake of clarity.

Fig. 2 (c-e) show the creation of electric field at point P at later times during the generator cycle. In each part, the field produced earlier in the sequence continue propagating towards the right. Fig. 2(d) shows the charge on the wires when the polarity of the generator has reversed, the top wire is negative and the bottom wire is positive. As a result, the electric field at P has reversed its direction and points upward. In part e of the sequence, a complete sine wave has been drawn through the tips of the electric field vectors to emphasize that the field changes sinusoidally.

Alongwith the electric field, a magnetic field B is also created, because the charges flowing in the antenna constitute an electric current, which produces a magnetic field. With the help of right hand rule (thumb of right hand points along the current I , fingers curl in the direction of B), the magnetic field can be seen to point into the page. As the oscillating current changes, the magnetic field change accordingly. The magnetic fields created at earlier times propagate outwards as a wave, just as the electric fields do. Fig.3 shows instantaneous pattern of electric and magnetic field lines due to an oscillating dipole. Lines show electric field and dots and crosses indicate magnetic field.

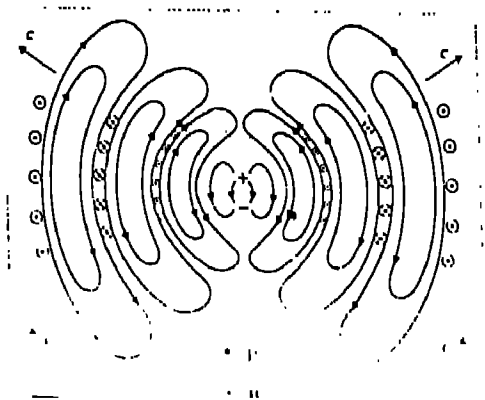


Fig.3-Instantaneous pattern of the electric and magnetic field lines due to an oscillating dipole. The electric fields are shown by lines and magnetic fields by dots and crosses.

Magnetic field is perpendicular to the page, whereas the electric field lies in the plane of the page. Thus the electric and magnetic fields created by the antenna are mutually perpendicular and remain so as they move outward. Moreover, both fields are perpendicular to the direction of travel. These perpendicular electrical and magnetic fields, moving together, constitute an electromagnetic wave. B is at maximum, wherever E is at maximum, i.e. electric and magnetic fields are in phase. It has been shown in fig.4 (a) and (b).

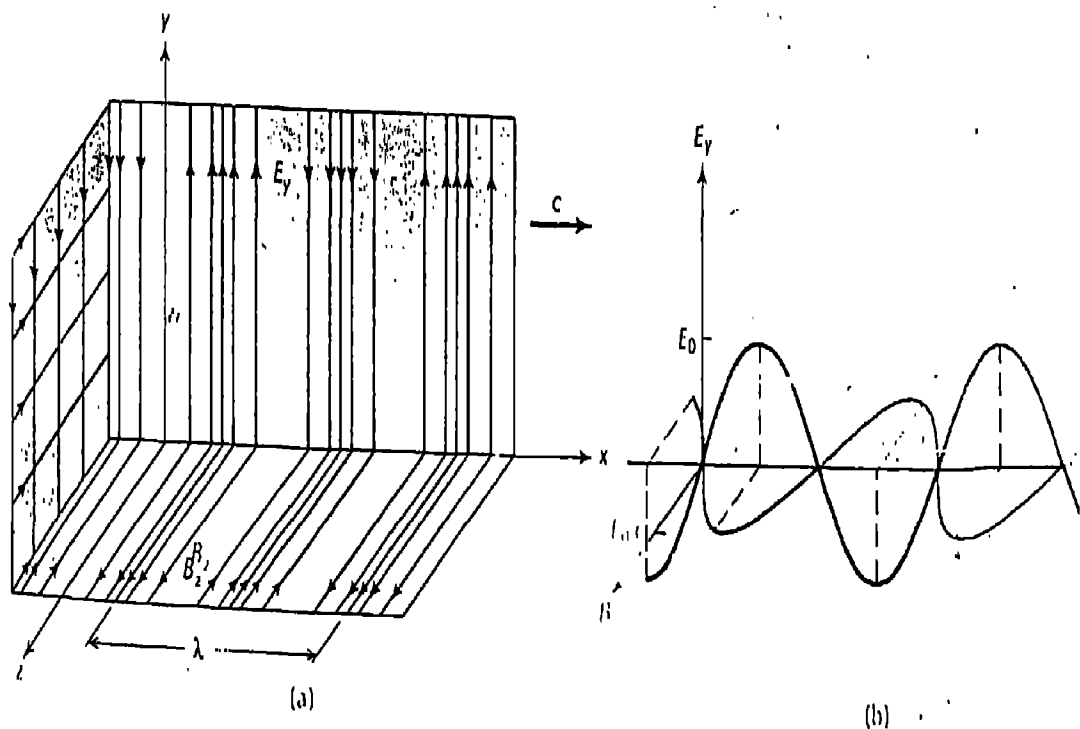


Fig. 4(a) Electric and magnetic field lines of a plane harmonic electromagnetic wave travelling towards the right shown at one instant of time. The electric field is vertical and the magnetic field is horizontal. The field lines fill all of spaces, but this diagram shows

only the field lines in the x - y plane, in the x - z plane and on a wave front. The distribution of field lines over the wave front is uniform, that is the electric and magnetic fields are constant over the wave front.

Fig 4(b) shows plot of the strength of the electric and magnetic fields as a function of x .

ELEMENTARY PARTICLES

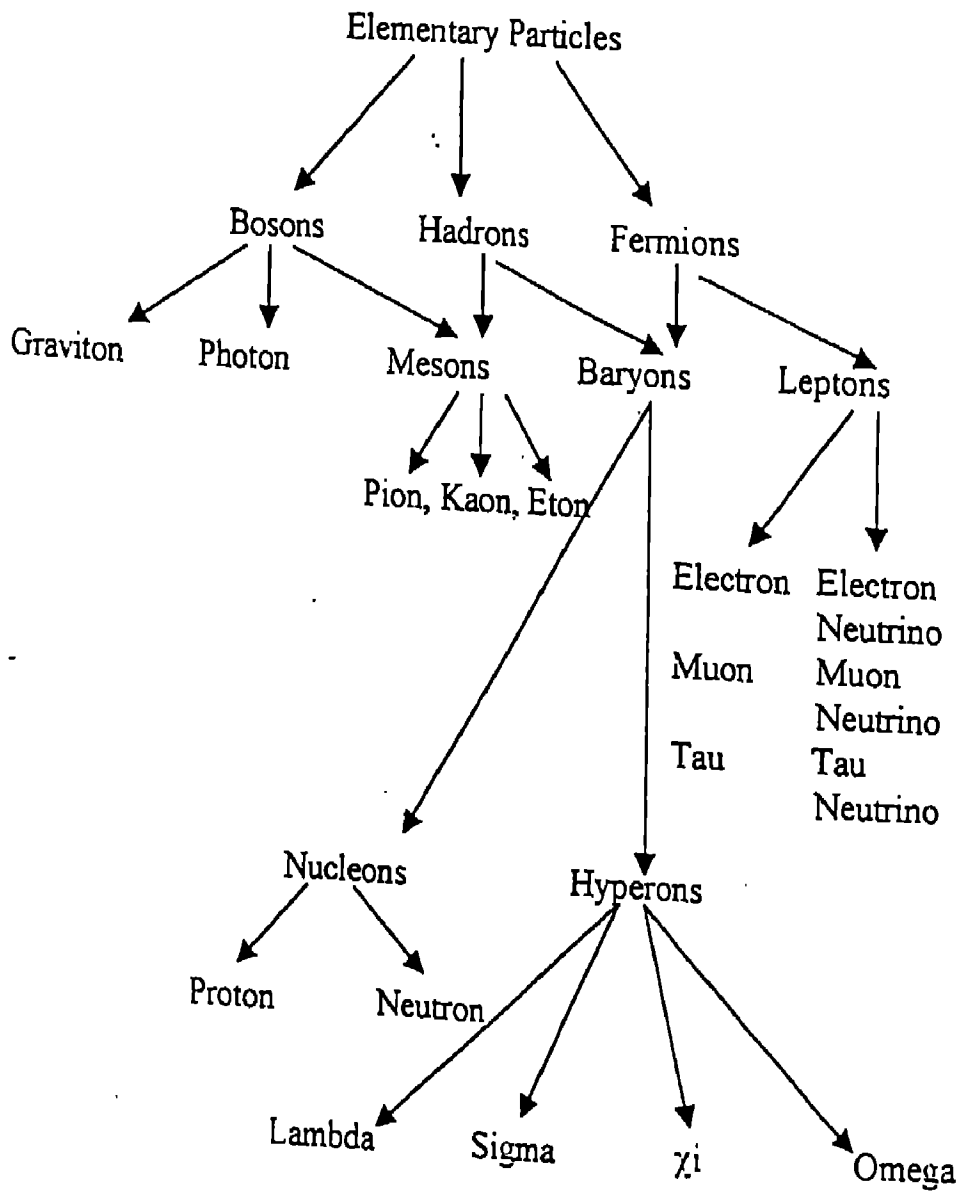
Prof. H. C. Jain.

Elementary particles are such micro-particles whose internal structure at present can't be presented as the combination of other particles. Each of them behaves like a single whole. Elementary particles can transform into one another.

Elementary Particles :

Particle	Symbol	Rest mass (in units of m_e)	Rest energy (MeV)	Charge (in units of e)	Spin (In terms of $\frac{h}{2\pi}$)	Antiparticle
Massless bosons						
Graviton	G	0	0	0	2	$\bar{g}$
Photon	γ	0	0	0	1	γ
Leptons (fermions)						
Neutrino	ν	0	0	0	$\frac{1}{2}$	$\bar{\nu}$
Electron	e^-	1	0.511	-1	$\frac{1}{2}$	e^+
Muon	μ^-	206.8	105.7	-1	$\frac{1}{2}$	μ^+
Mesons (Bosons)						
Pion	π^+	273.9	140	+1	0	π^-
	π^0	264.2	135	0	0	π^0
Kaon	K^+	966.7	494	+1	0	K^-
	K^0	974.6	498	0	0	K^0
Eton	η^0	1074	549	0	0	η^0
Baryons (Fermions)						
Nucleons						
Proton	p^+	1836.2	938.3	+1	$\frac{1}{2}$	$\bar{p}^-$
Neutron	n^0	1838.7	939.6	0	$\frac{1}{2}$	$\bar{n}^0$
Hyperons						
Lambda	λ^0	2184	1116	0	$\frac{1}{2}$	$\bar{\lambda}^0$
Sigma	Σ^-	2327	1189	+1	$\frac{1}{2}$	$\bar{\Sigma}^+$

	Σ^0	2333	1192	0	$\frac{1}{2}$	$\bar{\Sigma}^0$
	Σ^-	2342	1197	-1	$\frac{1}{2}$	$\bar{\Sigma}^+$
Λ^0	Ξ^0	2573	1315	0	$\frac{1}{2}$	$\bar{\Xi}^0$
	Ξ^-	2585	1321	-1	$\frac{1}{2}$	$\bar{\Xi}^+$
Omega	Ω^-	3276	1614	-1	$\frac{3}{2}$	$\bar{\Omega}^+$



Conservation Laws

- (i) Conservation of Momentum
- (ii) Conservation of Angular Momentum
- (iii) Conservation of energy
- (iv) Conservation of charge

(ii) Unification partial

Now Super-string theory

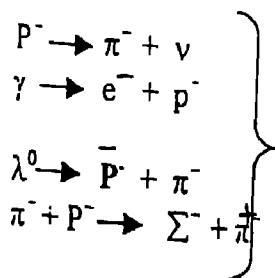
Basic constituents are not point objects but string of length 10^{-33} cm. Quarks, leptons and gauge bosons are different modes of such strings.

Particle			Antiparticle		
Protons	P	uud	Anti-Proton	$\bar{p}$	$\bar{u}\bar{u}\bar{d}$
Neutrons	N	udd	Anti-Neutron	$\bar{n}$	$\bar{u}\bar{d}\bar{d}$
Pi plus	π^+	ud	Pi-minus	π^-	$\bar{u}\bar{d}$
Pi Zero	π^0	$u\bar{u} + d\bar{d}$	Anti pi zero	π^0	$u\bar{u} + d\bar{d}$
K Zero	K^0	$d\bar{s}$	Anti k Zero	$\bar{K}^0$	$\bar{d}s$
B Zero	B^0	$d\bar{b}$	Anti B Zero	$\bar{B}^0$	$\bar{d}b$

Four kinds of interactions between elementary particles are known/. Intensity and strength of interaction is characterized by coupling constant (a dimensionless parameter). This parameter determines the probability of processes due to given interaction

Kinds of interaction	Coupling Constant	Radius of action	Where it acts
Strong	01	10^{-15} m	Amongst nucleons
Electromagnetic	10^{-2}	Infinity	Electric & Magnetic fields
Weak	10^{-14}	Short range 10^{-18} m	Beta decay
Gravitational	10^{-39}	Infinity	Between particles and bodies

- (v) Conservation of Leptons
- (vi) Conservation of Baryons
- (vii) Conservation of Isotopic Spin
- (viii) Conservation of Strangeness.



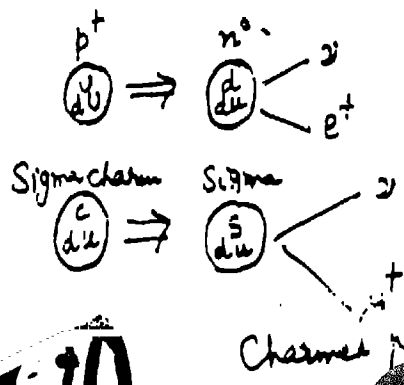
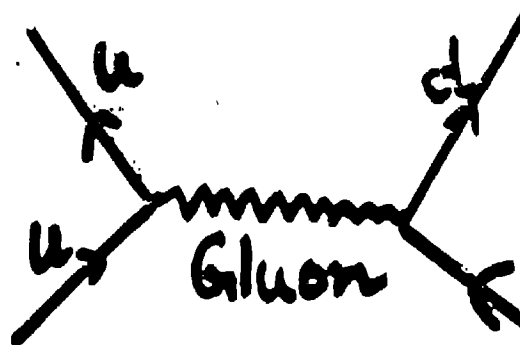
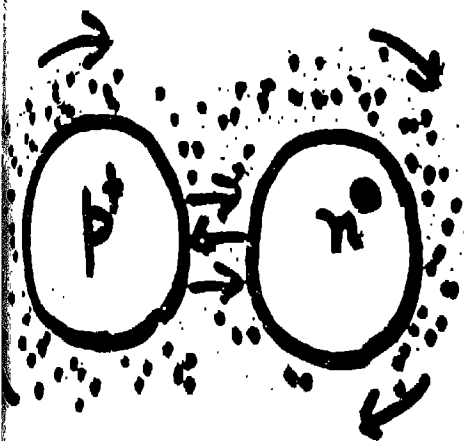
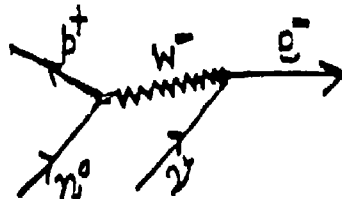
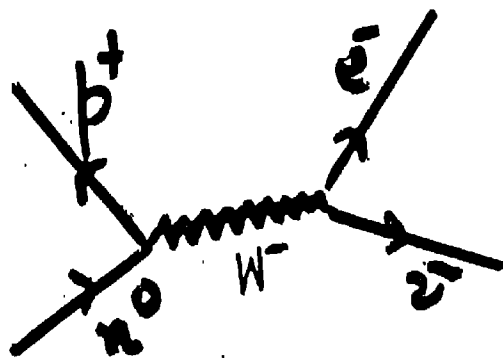
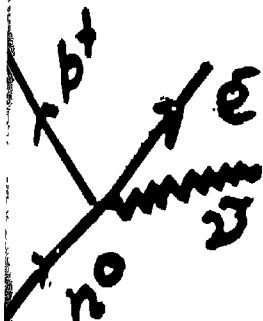
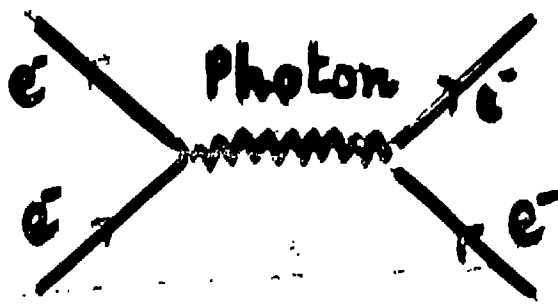
Not possible Why ?

Standard Model of Particle Physics for Matter

Quarks		Leptons		
Are held together inside particles by strong force. They change from one variety to another via the weak force		Don't feel the strong or but change from one generation to another via the weak force.		
	Mass (Gev)	Mass (Gev)		
Up (+2/3)	0.03	Electron (-1)	0.0005	1 st Gen.
Down (-1/3)	0.06	Electron Neutrino (0)	0?	
Charm (+2/3)	1.3	Muon (-1)	0.106	2 nd Gen.
Strange (-1/3)	0.14	Muon Neutrino (0)	0?	
Top (+2/3)	174	Tau (-1)	1.7	3 rd Gen.
Bottom (-1/3)	4.3	Tau Neutrino (0)	0?	

Basic Problems

- (i) What is the mechanism for generating masses for quarks ?
Leptons? Massive gauge bosons?



(10^{28} to 10^{33} years)

Radioactive Processes, Fission & Fusion

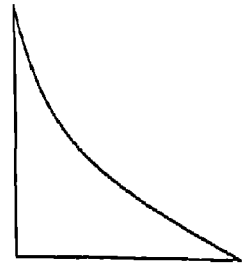
Prof. H. C. Jain

Some nuclei have a combination of protons and neutrons, which does not lead to stable configuration. They are unstable or radioactive. Radioactive processes include: (i) α decay (ii) β decay (including capture of electron) (iii) γ radiation of nuclei (iv) Spontaneous fission of heavy nuclei. (v) Proton radioactivity. Radioactivity under natural conditions is known as natural and radioactivity obtained as a result of nuclear reactions is known as artificial..

There is no difference between natural and artificial radioactivity. They obey same laws.

Law of radioactive transformation:

$$N = N_0 e^{-\lambda t}$$



$\lambda \rightarrow$ Decay constant; N_0 Number of nuclei at initial moment, $N \rightarrow$ Number of undecayed atoms at time t , activity $= \lambda N$.

$\therefore$ No. of nuclei decayed during time t

$$= N_0 - N = N_0 (1 - e^{-\lambda t})$$

Half Life: The time during which a half of initial number of nuclei decays and denoted by T

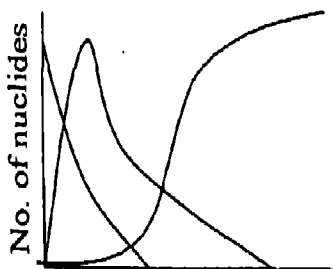
$$T = 0.693/\lambda$$

Mean life: Average lifetime of a nucleus is equal to $1/\lambda$

At times nuclei and further nuclei appearing as a result of successive radioactive transformation are also radioactive. So there is a full series.

In nature there are three radioactive series whose parents are U^{238} (Uranium series, $4n+2$), Th^{232} (Thorium series $4n$) & U^{235} (actinouranium series, $4n+3$)

Final product in all three series are Pb isotopes viz. Pb^{206} , Pb^{208} & Pb^{207} respectively.



N_P No. of atoms of Parent
 N_D No. of atoms of Daughter
 N_G No. of atoms of Grand Daughter

Law of successive radioactive transformation

$$N = N_G^0 \left(1 + \frac{\lambda_P}{\lambda_D - \lambda_P} \right) e^{-\lambda_D t} - \frac{\lambda_D}{\lambda_D - \lambda_P} e^{-\lambda_P t}$$

Radioactive equilibrium:

$$\frac{dN_p}{dt} = \frac{dN_D}{dt} = \frac{dN_{G_i}}{dt} = 0$$

$$\therefore \lambda_p N_p = \lambda_{G_i} N_{G_i} \text{ etc.}$$

Units of radioactivity:

- (i) Curie (Ci): 3.7×10^{10} disintegrations/second
(Based on disintegration of 1 gm Ra/Sec.)
- (ii) Rutherford (Rd): Amount of radioactive substance, which gives 10^6 disintegrations/second.
- (iii) Becquerel (Bq): Decay of one atom/second

$$1 \text{ Ci} = 37 \text{ billion becquerels}$$

Rad: Absorbed dose of 100 ergs/gm.

Gray: J/Kg (1 Gy = 100 rad)

Rem: Dose in Rad $\times$ Radiation weighting factor

Sievert (Sv): Dose in Gray $\times$ Radiation weighting factor.

Radioactive dating:

To determine age of rocks, earth, history of planet solar system etc.

$$N = N_0 e^{-\lambda t}$$

$$\lambda = 1/\tau$$

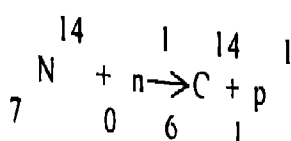
$$N = N_0 e^{-t/\tau}$$

$$t = \tau \log_e (N_0/N)$$

$$\text{Or } t = \tau_p \log_e (P + D/P)$$

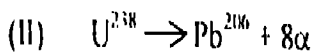
$\tau_p \rightarrow$ Life time of parent species, $P \rightarrow$ Abundances of unstable parent,
 $D \rightarrow$ Abundance of stable daughter element, P & D are determined by mass spectrometer,
assuming at $t = 0$, only parent species existed and at time t it decayed to produce daughter
nuclei D and left P parent nuclei.

Carbon Dating:



$C^{14} \rightarrow$ Radioactive (5730 is half life) gives β emission i.e. ${}^7N^{14} + {}_{-1}e^0 + \nu$

CO_2 molecules in air contain C^{14} & also C^{12} . Living organisms e.g. plants & trees take CO_2 which contain C^{14} & C^{12} . When organism dies, intake of C^{14} stops and C^{14} starts decaying with H.L. 5730 years. Thus knowing relative amounts of C^{12} & C^{14} , the number of years, the organism has been dead can be determined. Amount of C^{14} is determined by activity $\lambda N = A$

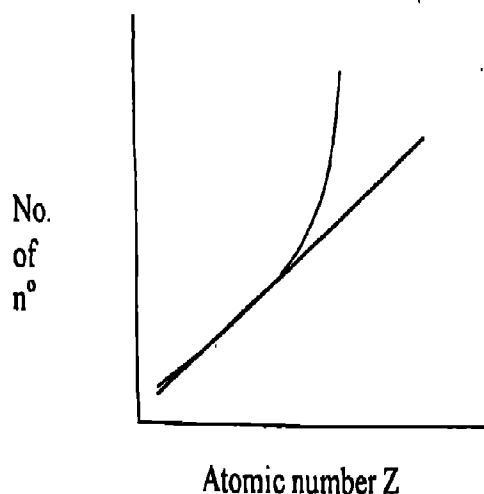


$$\text{Age of mineral} = \frac{\text{wt. of Pb } 206}{\text{Wt of } U^{238}} \times 7.5 \times 10^9 \text{ years}$$

If He is extracted

$$\text{Age of mineral} = \frac{\text{Wt. of He}}{\text{Wt. of } U^{238}} \times 8.6 \times 10^6 \text{ years}$$

Stability of nuclei
Segre chart



Isotopes – Identical Z, different A

Isobars – Same A, Isotones – same n^0

Isomers – Identical Z, identical A but different half life

$$M(Z, A) = ZM_H + (A - Z)M_n - a_1 A + a_2 A^{2/3} + a_3 \frac{Z^2}{A^{1/3}}$$

Mass of nucleus
volume energy
surface
Coulomb

Correction
energy correction
energy

correction

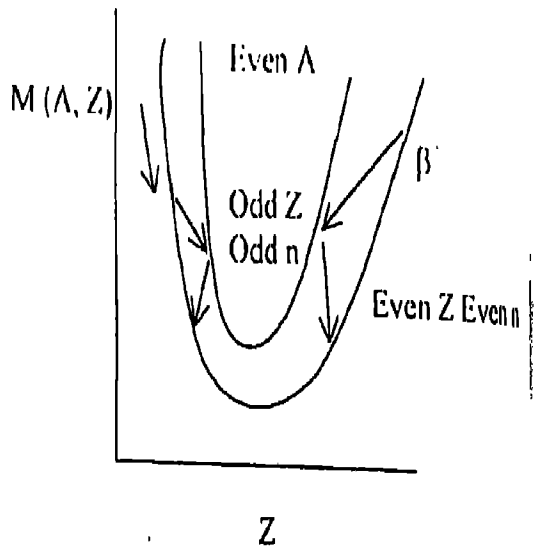
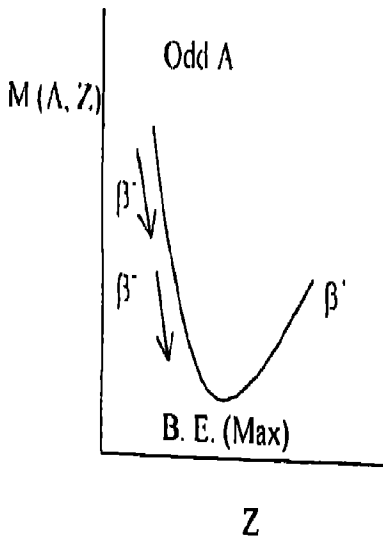
$$+ a_4 \frac{(A-2Z)^2}{A} \pm \delta$$

Asymmetric energy pairing energy

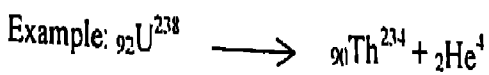
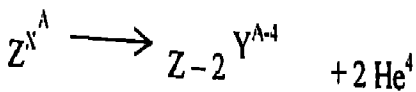
(+ for even even nuclei
0 for even odd or odd even nuclei)

$$\frac{\partial M}{\partial Z} = (M_H - M_n) + \frac{2a_3}{A^{1/3}} Z - \frac{a_4}{A} 2(A-2Z)(-2) = 0$$

$$Z = \frac{(M_n - M_H) + 4a_1}{\frac{8a_1}{\Lambda} + \frac{\Lambda^2}{4} + a_2}$$

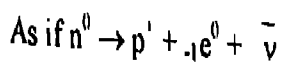
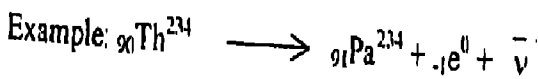
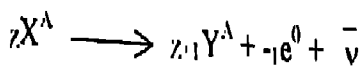


α - Decay:

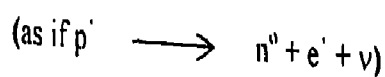
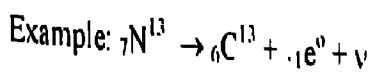
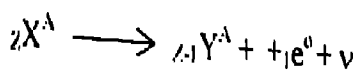


β - Decay:

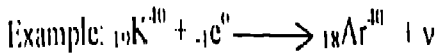
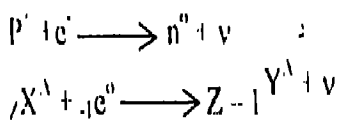
(a) Emission of electrons



(b) Emission of Positrons



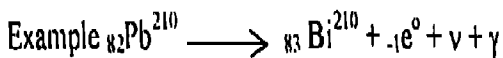
(c) Capture of an electron



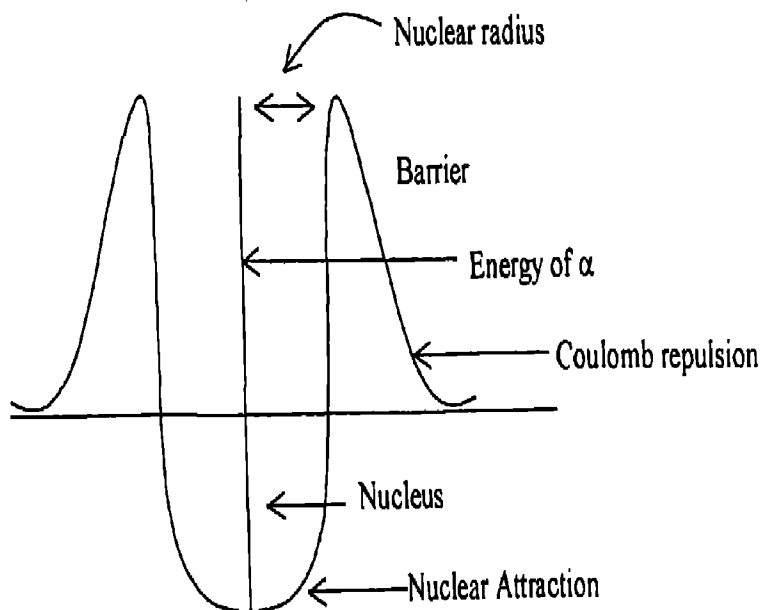
γ Rays For many radioactive elements,

γ radiations are given just after emission of α & β .

- are e.m. radiations like x-rays but with much low wavelength.
- originate from nucleus & not due to orbital electrons.
- are due to transition of one nucleon into another nucleon.
- preceded by α & β and evidence to prove that they originate from daughter nucleus.

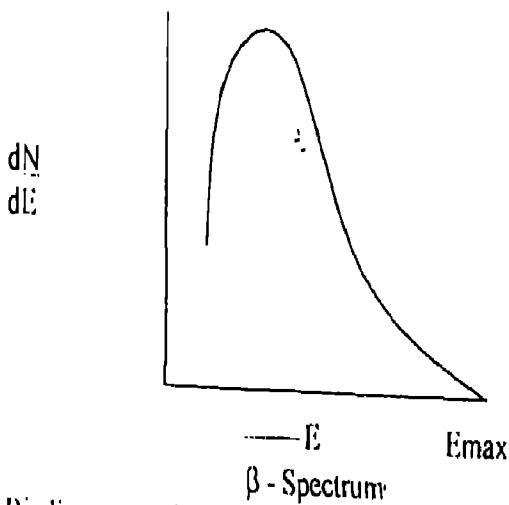


Classically, as per the energy of the ejected α particles, it is not possible for them to cross the potential barrier and come out of the nuclei. However, quantum mechanical calculations do show that there is a definite probability for them to cross this barrier. This effect is interpreted in terms of 'tunnel effect'.

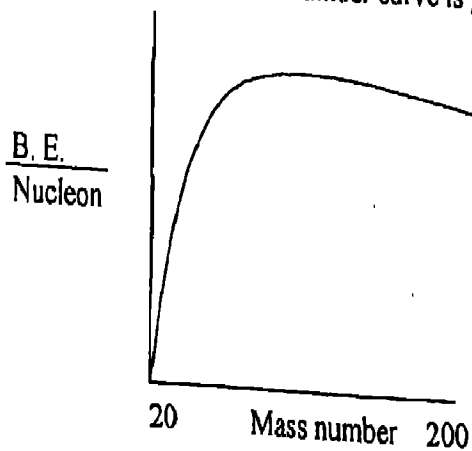


In case of β -decay, as per neutrino hypothesis, the emission of e^- and e^+ is accompanied by the emission of antineutrino or neutrino as well. This provides an explanation for particles emitted at different energies. Also it satisfies the requirement of spin.

Electrons cannot be part of the nucleus, though they are ejected from the nucleus. This can be explained in terms of (a) net magnetic moment (b) the energy of the released electron and calculations done using Heisenberg uncertainty principle.



Binding energy/nucleon vs mass number curve is given below:



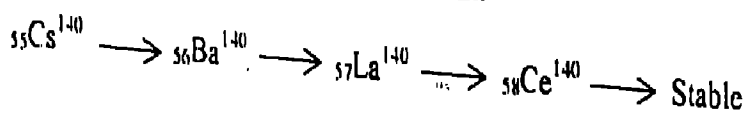
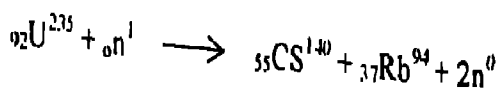
$$E_b = c^2 \{ [(Zm_p + (A-Z)m_n) - m_{\text{nuc}}] \}$$

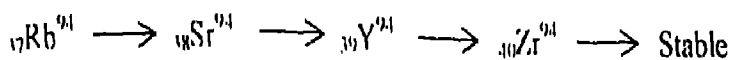
$$\frac{E_b}{A} \rightarrow \frac{\text{Binding energy}}{\text{Nucleon}}, \quad \frac{E_b}{c^2} \rightarrow \text{Mass defect}$$

Binding energy – It is equal to work that must be done to separate nucleons-forming nucleus and to remove them from one another to distances virtually excluding their interaction.

Fission and fusion, both lead to releasing of energy as the binding energy/nucleon increases whether we break up heavy nuclei into smaller ones or we fuse two light nuclei into a relatively heavy one.

Heavy nuclei when bombarded with neutron break up into fragments, a process known as nuclear fission and this process is accompanied by about 200 MeV energy as can be seen from the follow calculations:

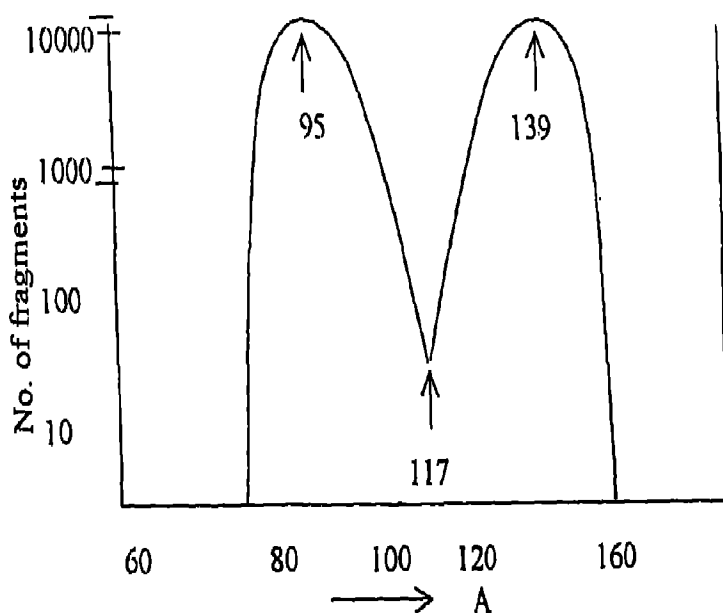




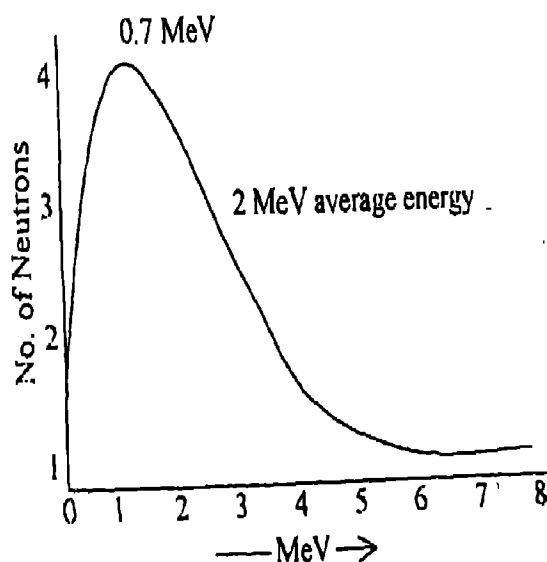
Before fission		After fission	
235			
U	235.043933	2 Fragments	232.812000
n	1.008665	3n	3.025995
236.052598		235.837995	

$$m = 0.214603 \text{ a.m.u} \Rightarrow \cdot 931 = 200 \text{ MeV}$$

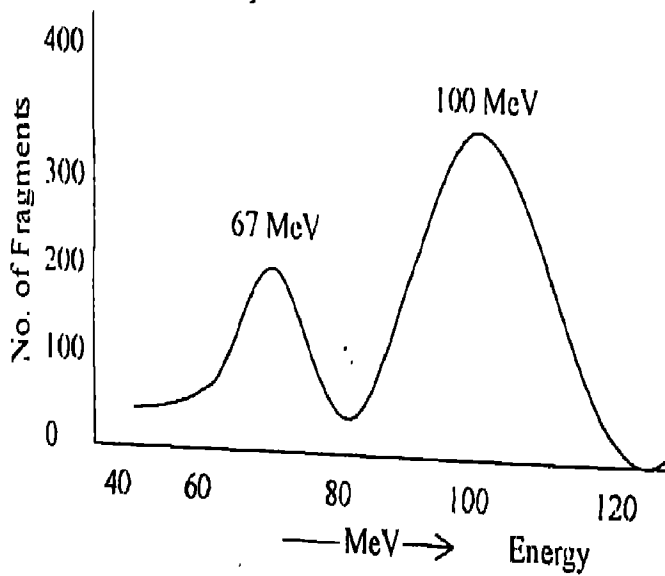
Here calculation has been done on the basis of two typical fragments accompanied by 3 neutrons. In practice, results of various experiments show that there can be fragments of various mass numbers. Most probable having their mass ratio is 2:3.



Similarly, the number of neutrons released also varies in fission reaction. On average 2 to 3 neutrons are released. Experiments show the following:

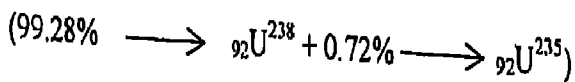


The following curve is obtained for number of fragments versus their kinetic energy



Features of an atomic reactor are:

1. Fuel – Natural Uranium



- Enriched Uranium ($> 0.72\% \longrightarrow {}_{92}\text{U}^{235}$)

- ${}_{92}\text{U}^{239}$, ${}_{92}\text{U}^{233}$

2. Neutron energy – Low energy or Thermal, Intermediate and high

3. Moderator - Heavy water, Graphite, Beryllium oxide, Water

4. Coolant - Air, CO_2 , or He, H_2O , Liquid metal e.g. Na, K

5. Control Rods - Cadmium or Boron rods

6. Radiation Shield

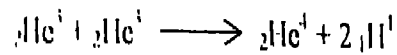
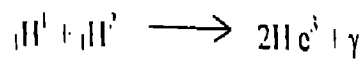
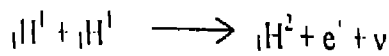
Fast breeder reactors don't use any moderator. India is the sixth country to have such a reactor with Plutonium – Uranium carbide fuel.

Fusion:

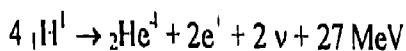
In sun, every second 564 million tons of hydrogen is converted into 560 million tons of helium and the remaining mass into energy (about 3.6×10^{26} J/sec) in accordance with Einstein's – mass energy relation $E = mc^2$. Even at this rate, sun may have a life of about 10^{12} years, as its mass is enormous (10^{30} Kg.).

Typical thermonuclear reactions happening in sun and other stars may be interpreted in terms of

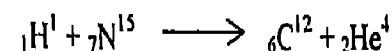
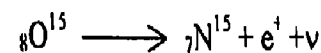
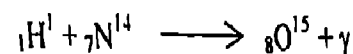
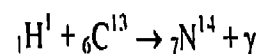
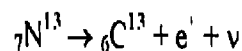
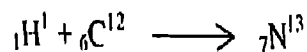
P - P cycle or C - N cycle.



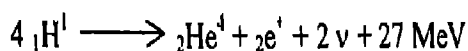
Summing up



$$(4 \times 1.00813 - 4.00386 = 0.02866 \text{ a.m.u.}) \implies 0.02866 \times 931 \text{ MeV} = 26.7 \text{ MeV}$$



Summing up

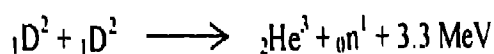


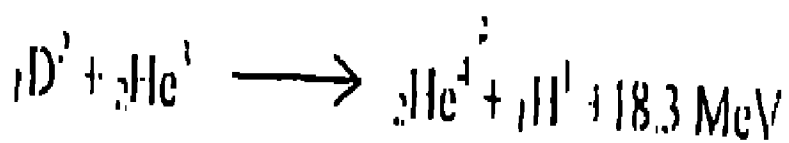
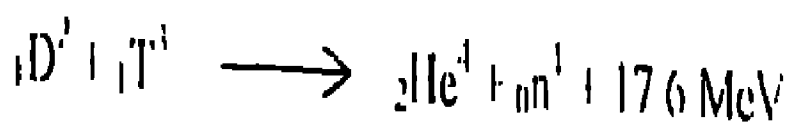
(The same as we have in P - P cycle)

P - P cycle happens at lower temperatures while C - N cycle takes place relatively at larger temperature.

Fusion reactions in laboratory

Seas and oceans have 0.015% (${}_1\text{D}^2$) amounting to 10^{15} tons





Lawson criterion ($n \tau \sim \Lambda$)

$$\Lambda \sim 10^{16} \text{ C m}^{-3} \text{ Sec (D - D)}$$

$$\Lambda \sim 10^{14} \text{ cm}^{-3} \text{ Sec. (D - T)}$$

Problems:

1. Temperature $> 10^8 \text{ K}$
2. Confinement
3. Heat Losses

Systems

1. Tokamaks
2. Stellators
3. Mirror Machine
4. Laser Fusion.

Some hard spots in thermodynamics

Ved Prakash Arya

Why upper atmosphere is cooled while its kinetic temperature is of the order of 1000k?

The quantity of heat (i.e. heat content) of an individual molecule in the upper atmosphere is increased about 3.5 times than that at the earth's surface. Kinetic temperature in the upper atmosphere is of the order of 1000k. But the pressure and hence according to $p = \frac{1}{3} \rho \overline{V^2}$ the density is very low in the upper atmosphere, i.e. in the upper atmosphere the number of molecules per c.c. is very small. Thus obviously the total heat content in the upper atmosphere is very small as compared to the heat content on the earth in the same volume of the gas. That is why upper atmosphere is cooled.

Kinetic interpretation of temperature

The average translational kinetic energy of a gas molecule is defined as $E = \frac{3}{2} K_B T$. This equation expresses the fact that the average kinetic energy per molecule of an ideal gas is proportional to the absolute temperature of the gas. At $T=0$, $E=0$. This implies that at absolute zero of temperature, the gas molecules will be devoid of all motion. This is the kinetic or molecular interpretation of absolute zero. It is remarkable that the average kinetic energy of a molecule is independent of pressure, volume or the type of the molecules.

Concept of an ideal gas:

Experiments have found that if we confine 1 mole samples of various gases in boxes of identical volume and hold the gases at the same temperature, then their measured pressures are nearly – though not exactly the same. At lower gas densities, these small differences in the pressure tend to disappear. At low enough densities, all real gases tend to obey the relation.

$$PV = nRT = NKT$$

Called ideal gas law, where n is the number of moles of gas present and N is the number of molecules.

Although there is no such thing in nature as a truly ideal gas, all real gases approach the ideal state at very low densities – when their molecules are far enough apart that they do not interact with one another. Thus, the ideal gas concept allows us to gain useful insights into the limiting behaviour of real gases.

Degrees of Freedom:

The degree of freedom of a system is defined as the number of independent coordinates required to specify its position. An ant moving on a taut string has only one d.f. Here we required a single coordinate with any point on the string as origin to specify the position of the ant. An ant walking on the floor has 2 d.f. when it can fly, it has 3 d.f. A point moving along a curved path on a plane has 1 d.f. Though two coordinates x and y will be required to specify motion, yet only one is independent. (They have to satisfy the equation of the curve). We say that the equation of the curve is a constraint, i.e. a restriction imposed on the system. The number of d.f. (f) of a system can be determined from $f = 3p - c$ ($c < 3p$)

Where p is the number of particles constituting the system and c the total number of constraints. For a single atom,

$$P = 1, c = 0, f = 3$$

For a diatomic molecule $p = 2$, $c = 1$ as the distance between the atoms is a fixed quantity. So $f = 5$

For CH_4 molecule,

$$P = 5, C = 9, f = 6$$

The number of d.f. can also be defined as the total number of independent squared terms appearing in the expression of energy of a system. Each degree of freedom has associated with it – on average – an energy of $\frac{1}{2} kT$ per molecule (or $\frac{1}{2} RT$ per mole).

All three types (monatomic, diatomic and polyatomic) of molecules can have translational motions (say, moving left-right and up-down) and rotational motions (spinning about an axis like a top). In addition, the diatomic and polyatomic molecules can have oscillatory motions, with the atoms oscillating slightly toward and away from one another, as if attached to opposite ends of a spring.

Quantum theory of specific heat

Experiment shows that the oscillations of the atoms in a gas of diatomic or polyatomic molecules occur only at relatively high temperatures of the gas – the motion is “turned on” only when the gas molecules have relatively large energies. Rotational motion is also subject to such “turning on” but at a lower temperature.

The ratio C_v/R for diatomic hydrogen gas (H_2) below about 80K, is 1.5 means only translational degrees of freedom of H_2 are involved in the specific heat. As the temperature increases, the value of C_v/R gradually increases to 2.5 implying that two additional degrees of freedom have become involved. As the temperature increases beyond 1000K, the number of molecules with enough

energy to oscillate increases and C_v/R becomes 3.5. At very high temperature, the molecule will dissociate into separate atoms.

Why water evaporates at low temperatures, while boiling occurs at 100°C ?

In first sight, it is true that liquid state of water converts into vapour state at 100°C . Answer of the above question is supplied by Maxwell's speed distribution law, according to which the number of molecules having speeds in a certain range v and $v+dv$,

$$dN_v = 4\pi N \left(\frac{m}{2\pi k_B T}\right)^{3/2} e^{-\frac{mv^2}{2k_B T}} v^2 dv$$

From nature of $fv (= \frac{dN_v}{dv}) - v$ curve it is clear that the function fv increases, takes a maximum value and then decreases exponentially. So it is clear that some molecules have the higher enough velocity hence the kinetic energy to escape from the surface of the water. That is why evaporation occurs at low temperatures also.

Why smell of perfume is detected after some time?

The molecules of a gas move with very high speeds even at room temperature, so a given mass of a gas should diffuse instantaneously, while that is not so. Then, Is Maxwell distribution law wrong? No, but this is due to the assumption of 'point' molecules, which is equivalent to ignoring collisions between molecules. Actually, when a molecule of finite size moves in a gas, it collides with other molecules. As a result its direction frequently changes resulting in a series of short zig - zag paths. The path covered by a molecule between successive collisions is called a free path.

Why a high vacuum condition is required in a chamber for obtaining a well-directed molecules beam?

The expression for mean free path is

$$\lambda = \frac{1}{\sqrt{2}} \frac{1}{n} \frac{k_B T}{p}$$

At very low pressures (i.e. a high vacuum condition), the collisions occur essentially with the walls and mean free path becomes equal to the dimensions of the container and well-directed molecular beam can be obtained.

Misconception regarding mechanical equivalent of heat

The mechanical equivalent of heat is generally treated as some fundamental constant of physics and its unit is given.

Actually this is not so. It is just a conversion factor between two systems of units, viz. the work unit and the heat unit. Not any experiments are performed to determine the conversion factor between feet and meter, or between electron volt and Joule or between Celsius and Fahrenheit degree of temperature. Then why only for J, mechanical equivalent of heat? Actually, the significance of Joule's experiment in determining the J is quite different. In his times heat was

not identified as a form of energy. The comparison between different processes which produce the same rise in temperature of a substance, established that mechanical work (VIt) and heat were all quantities of the same type. The units of electricity were defined in a different system of units. So it was necessary to determine a conversion factor. But his aim was to show that heat produced was proportional to work done and that with proper choice of units the two would be identical quantities.

Is Newton's law of cooling a consequence of Stefan's law of radiation?

Generally, Newton's law of cooling is derived from Stefan's law without considering mode of heat transfer. What is still more important is that the temperature of the body in the context of Newton's law of cooling is not the temperature of the radiating surface as required by Stefan's law. Thus the derivation is not true both conceptually and mathematically. Newton's law of cooling is relevant to situations where heat conducted from a body is carried away by convection currents of fluids flowing over the surface of the body. The law is found to hold true even for large temperature differences when there is forced convection.

The radiation loss according to Stefan's law depends upon temperature of the outer surface of the calorimeter and not that of liquid in it and therefore the derivation of Newton's law from Stefan's law is impossible. The two laws refer to quite different temperatures.

The mathematics employed in the derivation is equally bad. If we call the temperature of the surrounding T and the temperature of the radiating surface $T + \Delta T$, then from Stefan's law, we get the rate of cooling of the body

$$-\frac{dQ}{dt} = \sigma \epsilon A T^3 (4\Delta T) \left[1 + \frac{3}{2} \frac{\Delta T}{T} + \left(\frac{\Delta T}{T}\right)^2 + \dots \right]$$

To show that approximately, $H = \text{Const. } \Delta T$, $\Delta T/T$ must be negligible compared to unity. To see that this is not so, let us consider some typical values of temperature. If we assume the room temperature to be 27°C and the temperature of the liquid in the calorimeter 87°C , $T = 300\text{K}$ and $\Delta T = 60\text{K}$. With these values $\Delta T/T = 0.2$. It is absurd to say that 0.2 is negligible in comparison to 1. In fact, the neglected term increases by more than one percent for every 2 degree rise in ΔT and the graph of dT/dt versus ΔT would be a curve with slope increasing instead of a straight line as required for Newton's law of cooling.

Process:

The transition from one equilibrium state to another, i.e. from some values P_1, V_1, T_1 of the parameters to others P_2, V_2, T_2 .

State with a different volume, if we do it rapidly, the pressure as well as temperature, will no longer be constant over the volume. Intermediate states in

such a process are non-equilibrium ones. Such process is called non-equilibrium process.

Obviously, a non-equilibrium process cannot be reversible, while an equilibrium process is always reversible. Some infinitely slow processes are irreversible. For example, the plastic deformation of solids may occur infinitely slowly, but is nevertheless an irreversible process. Infinitely slow isothermic expansion of a gas is reversible process.

Can hot water freeze faster than cold water?

I. Yes – a general explanation

Hot water can in fact freeze faster than cold water for a wide range of experimental conditions. This phenomenon is extremely counter – intuitive, and surprising even to most scientists, but it is in fact real. It has been seen and studied in numerous experiments. While this phenomenon has been known for centuries, and was described by Aristotle, Bacon, and Descartes, it was not introduced to the modern scientific community until 1969, by a Tanzanian high school student named Mpemba. Both the early scientific history of this effect, and the story of Mpemba's rediscovery of it, are interesting in their own right – Mpemba's story in particular provides a dramatic parable against making snap judgements about what is impossible. This is described separately below.

The phenomenon that hot water may freeze faster than cold is often called the Mpemba effect. Because, no doubt, most readers are extremely skeptical at this point, we should begin by stating precisely what we mean by the Mpemba effect. We start with two containers of water, which are identical in shape, and which hold identical amounts of water. The only difference between the two is that the water in one is at a higher (uniform) temperature than the water in the other. Now we cool both containers, using the exact same cooling process for each container. Under some conditions the initially warmer water will freeze first. If this occurs, we have seen the Mpemba effect. Of course, the initially warmer water will not freeze before the initially cooler water for all initial conditions. If the hot water starts at 99.9°C and the cold water at 0.01°C , then clearly under those circumstances, the initially cooler water will freeze first. However, under some conditions the initially warmer water will freeze first – if that happens, you have seen the Mpemba effect. But you will not see the Mpemba effect for just any initial temperatures, container shapes, or cooling conditions.

This seems impossible, right? Many sharp readers may have already come up with a common proof that the Mpemba effect is impossible. The proof usually goes something like this. Say that the initially cooler water starts at 30°C and takes 10 minutes to freeze, while the initially warmer water starts out at 70°C . Now the initially warmer water has to spend some time cooling to get

down to 30°C , and after that, it's going to take 10 more minutes to freeze. So since the initially warmer water has to do everything that the initially cooler water has to do, plus a little more, it will take at least a little longer, right? What can be wrong with this proof?

What's wrong with this proof is that it implicitly assumes that the water is characterized solely by a single number – the average temperature. But if other factors besides the average temperature are important, then when the initially warmer water has cooled to an average temperature of 30°C , it may look very different than the initially cooler water (at a uniform 30°C) did at the start. Why? Because the water may have changed when it cooled down from a uniform 70°C to an average 30°C . It could have less mass, less dissolved gas, or convection currents producing a non-uniform temperature distribution. Or it could have changed the environment around the container in the refrigerator. All four of these changes are conceivably important, and each will be considered separately below. So the impossibility proof given above doesn't work. And in fact the Mpemba effect has been observed in a number of controlled experiments. It is still not known exactly why this happens. A number of possible explanations for the effect have been proposed, but so far the experiments do not show clearly which, if any, of the proposed mechanisms is the most important one. While you will often hear confident claims that X is the cause of the Mpemba effect, such claims are usually based on guesswork, or on looking at the evidence in only a few papers and ignoring the rest. Of course, there is nothing wrong with informed theoretical guesswork or being selective in which experimental results you trust – the problem is that different people make different claims as to what X is.

Why hasn't modern science answered this seemingly simple question about cooling water? The main problem is that the time it takes water to freeze is highly sensitive to a number of details in the experimental set – up, such as the shape and size of the container, the shape and size of the refrigeration unit, the gas and impurity content of the water, how the time of freezing is defined, and so on. Because of this sensitivity, while experiments have generally agreed that the Mpemba effect occurs, they disagree over the conditions under which it occurs, and thus about why it occurs. As Firth wrote "There is a wealth of experimental variation in the problem so that any laboratory undertaking such investigations is guaranteed different results from all others".

So with the limited number of experiments done, often under very different conditions, none of the proposed mechanisms can be confidently proclaimed as "the" mechanism. Above we described four ways in which the initially warmer water could have changed upon cooling to the initial temperature of the initially cooler water. What follows below is a short

description of the four related mechanisms that have been suggested to explain the Mpemba effect. More ambitious readers can follow the links to more complete explanations of the mechanisms, as well as counter – arguments and experiments that the mechanisms cannot explain. It seems likely that there is no one mechanism that explains the Mpemba effect for all circumstances, but that different mechanisms are important under different conditions.

1. Evaporation – As the initially warmer water-cools to the initial temperature of the initially cooler water, it may lose significant amounts of water to evaporation. The reduced mass will make it easier for the water to cool and freeze. Then the initially warmer water can freeze before the initially cooler water, but will make less ice. Theoretical calculations have shown that evaporation can explain the Mpemba effect if you assume that the water loses heat solely through evaporation. This explanation is solid, intuitive, and evaporation is undoubtedly important in most situations. However, it is not the only mechanism. Evaporation cannot explain experiments that were done in closed containers, where no mass was lost to evaporation. And many scientists have claimed that evaporation alone is insufficient to explain their results.
2. Dissolved Gasses – Hot water can hold less dissolved gas than cold water, and large amounts of gas escape upon boiling. So the initially warmer water may have less dissolved gas than the initially cooler water. It has been speculated that this changes the properties of the water in some way, perhaps making it easier to develop convection currents (and thus making it easier to cool), or decreasing the amount of heat required to freeze a unit mass of water, or changing the boiling point. There are some experiments that favor this explanation, but no supporting theoretical calculations.
3. Convection – As the water cools it will eventually develop convection currents and a non-uniform temperature distribution. At most temperatures, density decreases with increasing temperature, and so the surface of the water will be warmer than the bottom – this has been called a “hot top”. Now if the water loses heat primarily through the surface, then water with a “hot top” will lose heat faster than we would expect based on its average temperature. When the initially warmer water has cooled to an average temperature the same as the initial temperature of the initially cooler water, it will have a “hot top” and thus its rate of cooling will be faster than the rate of cooling of the initially cooler water at the same average temperature. Got all that? You might want to read this paragraph again, paying careful distinction to the difference between initial temperature, average temperature, and temperature. While experiments have seen the “hot top”, and related

convection currents, it is unknown whether convection can by itself explain the Mpemba effect.

4. Surroundings – A final difference between the cooling of the two containers relates not to the water itself, but to the surrounding environment. The initially warmer water may change the environment around it in some complex fashion, and thus affect the cooling process. For example, if the container is sitting on a layer of frost which conducts heat poorly, the hot water may melt that layer of frost, and thus establish a better cooling system in the long run. Obviously explanations like this are not very general, since most experiments are not done with containers sitting on layers of frost.

Finally, supercooling may be important to the effect. Supercooling occurs when the water freezes not at 0°C , but at some lower temperature. One experiment found that the initially hot water would supercool less than the initially cold water. This would mean that the initially warmer water might freeze first because it would freeze at a higher temperature than the initially cooler water. If true, this would not fully explain the Mpemba effect, because we would still need to explain why initially warmer water supercools less than initially cooler water.

In short, hot water does freeze sooner than cold water under a wide range of circumstances. It is not impossible, and has been seen to occur in a number of experiments. However, despite claims often made by one source or another, there is no well – agreed explanation for how this phenomenon occurs. Different mechanisms have been proposed, but the experimental evidence is inconclusive. For those wishing to read more on the subject, Jearl Walker's article in *Scientific American* is very readable and has suggestions on how to do home experiments on the Mpemba effect, while the articles by Auerbach and Wojciechowski are two of the more modern papers on the effect.

II History of the Mpemba Effect

The fact that hot water freezes faster than cold has been known for many centuries. The earliest reference to this phenomenon dates back to Aristotle in 300 B.C. The phenomenon was later discussed in the medieval era, as European physicists struggled to come up with a theory of heat. But by the 20th century the phenomenon was only known as common folklore, until it was reintroduced to the scientific community in 1969 by Mpemba, a Tanzanian high school student. Since then, numerous experiments have confirmed the existence of the "Mpemba effect", but have not settled on any single explanation.

In 1963, Mpemba was making ice cream at school, which he did by mixing boiling milk with sugar. He was supposed to wait for the milk to cool before placing it in the refrigerator, but in a rush to get scarce refrigerator space, he put his milk in without cooling it. To his surprise, he found that his hot milk froze into ice cream before that of other students. He asked his physics teacher for an explanation, but was told that he must have been confused, since his observation was impossible.

Mpemba believed his teacher at the time. But later that year he met a friend of his who made and sold ice cream in Tanga town. His friend told Mpemba that when making ice cream, he put the hot liquids in the refrigerator to make them freeze faster. Mpemba found that other ice cream sellers in Tanga had the same practice.

Later, when in high school, Mpemba learned Newton's law of cooling, that described how hot bodies are supposed to cool (under certain simplifying assumptions). Mpemba asked his teacher why hot milk froze before cold milk when he put them in the freezer. The teacher answered that Mpemba must have been confused. When Mpemba kept arguing, the teacher said "All I can say is that is Mpemba's physics and not the universal physics" and from then on, the teacher and the class would criticize Mpemba's mistakes in mathematics and physics by saying "That is Mpemba's mathematics" or "That is Mpemba's Physics". But when Mpemba later tried the experiment with hot and cold water in the biology laboratory of his school, he again found that the hot water froze sooner.

Subsequent discussion of the effect has been inconclusive. While quite a few experiments have replicated the effect, there has been no consensus on what causes the effect. The different possible explanations are discussed above. The effect has repeatedly a topic of heated discussion in the "New Scientist", a popular science magazine. The letters have revealed that the effect was known by lay persons around the world long before 1969. Today, there is still no well-agreed explanation of the Mpemba effect.

The principle of increase of entropy

Consider the process, in which a quantity of heat δQ flows from the surroundings at temperature T_{surr} to the system at temperature T_{sys} . From the inequality of Clausius, we can write

$$\Delta S_{\text{sys}} \geq \delta Q / T_{\text{sys}}$$

For the surroundings, δQ is negative and we can write

$$\Delta S_{\text{surr}} = - \delta Q / T_{\text{surr}}$$

The net change of entropy of the universe is therefore

$$\begin{aligned} \Delta S_u &= \Delta S_{\text{sys}} + \Delta S_{\text{surr}} \geq \frac{\delta Q}{T_{\text{sys}}} - \frac{\delta Q}{T_{\text{surr}}} \\ &\geq \delta Q \left(\frac{1}{T_{\text{sys}}} - \frac{1}{T_{\text{surr}}} \right) \end{aligned}$$

Since $T_{\text{sur}} > T_{\text{sys}}$, the quantity within the bracket is positive and hence

$$\Delta S_{\text{un}} \geq 0$$

If $T_{\text{sys}} > T_{\text{sur}}$, the heat transfer is from system to surroundings and both δQ and the quantity $\left(\frac{1}{T_{\text{sys}}} - \frac{1}{T_{\text{sur}}}\right)$ will be negative, yielding the same result.

The equality and greater than signs hold for reversible and irreversible processes, respectively. Equation given above dictates unidirectionality for evolution of a process. This is also called second law of thermodynamics. We can say in the words of some physicists "In the gigantic factory of natural processes, the principle of entropy increase acts as a **factory manager**, determining the type and kind of business transaction performed, while the principle of conservation of energy plays the role of **accountant**, settling balances of debit and credit".

Entropy:

The future belongs to those who can manipulate entropy; those who understand but energy will be only the accountants ----- . The early industrial revolution involved energy, but the automatic factory of the future is an entropy revolution.

Erederic keffer

Laws of thermodynamics

1. "You can not win.
2. you cannot break even.
3. you cannot stop playing the game.

The first law tells us that heat is a form of energy and that it is conserved.

The second law prohibits certain energy conservation processes, even though the overall energy is conserved. All natural processes involving heat flow are irreversible. Entropy is a measure of microscopic disorder

$$S = k \ln W$$

$\Delta S_{\text{universe}} > 0$ For all natural (irreversible) processes

$\Delta S_{\text{universe}} = 0$ For reversible processes only. Entropy is a measure of the unavailability of energy for doing work.

Some humerist has pointed out that the second law proves. Hell must be a place that has the same temperature throughout. Otherwise, the resident thermodynamicists would use temperature difference to run a refrigerator to cool off a local region.

Energy and Entropy

Energy reigns over everything that occurs in infinite space and in the course of transient time. Energy like a **Queen or Goddess**, irradiate its light over everything from the blade of grass in the field to a man of genius, endowing here and bereaving there, while remaining constant in quantity. Yet, where there is light, there is shade.

Entropy is the name of the **queen's shadow**. Face to face with this phenomenon, Man cannot help feeling some vague fear: Entropy, like an evil spirit, tries to diminish or annihilate the best creations of that gracious spirit. Energy, we all are under the protection of energy and all the potential victims of the latent poison of entropy.

The quantity of energy is constant, whereas the quantity of entropy increases, depreciating energy qualitatively. The sun is shining but the shadows grow longer. Degradation, equalization, devaluation take place all around.

Both Energy and entropy are words of Greek Origin. The prefix 'en' means 'in' or 'content', ergon means 'work' and 'trap in' means 'to turn', change.

Scientists selected these terms to reflect the nature of their respective notions. A change in energy $\Delta E = E_1 - E_2$ in an isolated system indicates the maximum amount of work A_{max} that the system can theoretically produce in transition from state 1 to state 2.

A change in entropy $\Delta S = S_2 - S_1$ represent the store of energy ΔE converted into heat and dissipating i.e.

$$Q_0 = T_0 \Delta S$$

Under real conditions of transition and at T_0 ambient temperature, this store diminishes the amount of the actual work A_a to $A_a = A_{max} - T_0 \Delta S$.

Thus, we may say that the change in entropy characterizes the amount of energy degradation in the process of transformation.

Some Scientists, therefore concluded that eventually, perhaps after a very long time, all the energy available on this planet and in other parts of the universe would convert to heat. According to this theory, the even distribution of heat between terrestrial and universal bodies would result in temperature equalization and the complete heat of all energy transformations, i.e. a "**heat death of the universe**".

THERMOELECTRICITY

When two metals are placed in electric contact, electrons flow out of the one in which the electrons are less bound and into the other. The binding is measured by the location of the so-called Fermi level of electrons in the metal, the higher the level, the lower is the binding. The Fermi level represents the demarcation in energy within the conduction band of a metal between the energy levels occupied by electrons and those that are unoccupied. The energy of an electron at the Fermi level is $-W$ relative to free electron outside the metal. The flow of electrons between the two conductors in contact continues until the change in electrostatic potential brings the Fermi levels of the two metals (W_1 and W_2) to the same value. This electrostatic potential is called the contact potential P (sub 12) and is given by $e \phi$ (sub 12) = $W_1 - W_2$, where e is $1.6(\text{times } 10) \text{ sup-19 } \text{ coulomb}$ (1.6×10^{-19}).

If a closed circuit is made of two different metals there will be no net electromotive force in the circuit because the two contact potentials oppose each other and no ~~and~~ current will flow. There will be a current if the temperature of one of the junctions is raised with respect to that of the second. There is a net electromotive force generated in the circuit, as it is unlikely that the two metals will have Fermi levels with identical temperature dependence. To maintain the temperature difference, heat must enter the hot junction and leave the cold junction, this is consistent with the fact that the current can be used to do mechanical work. The generation of a thermal electromotive force at a junction is called the Seebeck

effect (after the Estonian-born German physicist Thomas Johann Seebeck). The electromotive force is approximately linear with the temperature difference between two junctions of dissimilar metals, which are called a thermocouple. For a thermocouple made of iron and constantan (an alloy of 60 percent copper and 40 percent nickel), the electromotive force is about five millivolts when the cold junction is at 0°C and the hot junction at 100°C . One of the principal applications of the Seebeck effect is the measurement of temperature. The chemical properties of the medium, the temperature of which is measured, and the sensitivity required dictate the choice of components of a thermocouple.

The absorption or release of heat at a junction in which there is an electric current is called the Peltier effect (after the French physicist Jean-Charles Peltier). Both the Seebeck and Peltier effects also occur at the junction between a metal and semiconductor and at the junction between two semiconductors. The development of semiconductor thermocouples (e.g. those consisting of n-type and p-type bismuth telluride) has made the use of the Peltier effect practical for refrigeration. Sets of such thermocouples are connected electrically in series and thermally in parallel. When an electric current is made to flow, a temperature difference, which depends on the current, develops between the two junctions. If the temperature of the hotter junction is kept low by removing heat, the second junction can be tens of degrees colder and act as a refrigerator. Peltier refrigerators are used to cool small bodies, they are compact, have no moving mechanical parts.

and can be regulated to maintain precise and stable temperatures. They are employed in numerous applications, as, for example, to keep the temperature of a sample constant while it is on a microscope stage.

What is the origin of thermo emf ?

Contact potential difference:-

At the end of the 18th century A. volta (1745-1827) observed that a contact potential difference is established between two different metals when they are in contact with each other. The origin of this potential difference can be explained by the electronic theory.

Let us consider two metals with different electron concentration ($n_1 > n_2$). Since the two metals have the same temperature at their place of contact, the average velocity of thermal motion of their electrons is also the same at this place. For simplicity let us suppose that their mean free paths are approximately the same as well. Owing to their thermal motion the electrons diffuse into the two metals. The number of electrons transferred from the first metal to the second is equal to one sixth the of the electrons contained in the layer of thickness λ , i.e.

$N_1 = \frac{1}{6} n_1 A \lambda$ The number of electrons transferred from second metal to the first is $N_2 = \frac{1}{6} n_2 A \lambda$. But since we specified that $n_1 > n_2$, the second metal acquires more electrons than it gives up to the first metal.

Hence, one metal becomes the positively charged as a result of diffusion. Diffusion in this case plays the same role as an extraneous field would at the place of contact. The flow of electrons from one metal to the

other ceases when the established potential difference counterbalance the emf of the extraneous field. Let us qualitatively assess the contact potential difference from the following considerations. The current in the contact layer is

$$i = \frac{\Delta Q}{\Delta t} = e \frac{(N_1 - N_2)}{\tau} = \frac{e \lambda A}{6 \tau} (n_1 - n_2) = \frac{e A U}{6} \cdot (n_1 - n_2) \quad \text{--- (1)}$$

According to Ohm's law the potential difference equals the product of the current by the resistance of the contact layers. This resistance is $R = R_1 + R_2 = \rho_1 \lambda / A + \rho_2 \lambda / A$

Where ρ_1 and ρ_2 are the resistivities of the layers combining (1) and (2)

$$R = \frac{2m\bar{u}^2}{e^2 A} \left(\frac{1}{n_1} + \frac{1}{n_2} \right)$$

$$\text{Thus } \Delta V = iR = \frac{m\bar{u}^2 (n_1 - n_2)}{3 e} \left(\frac{1}{n_1} + \frac{1}{n_2} \right) \quad \text{--- (3)}$$

After Substituting $\frac{3}{2} KT$ for $m\bar{u}^2$

$$\left(\frac{1}{2} m\bar{u}^2 = \frac{3}{2} KT \right)$$

$$V = \frac{kT}{e} \left\{ \frac{n_1}{n_2} - \frac{n_2}{n_1} \right\} \quad \text{--- (4)}$$

Contact potential difference depends, only on the temperature and the chemical compositions of the metals (Thermoelectric Series)

Thermoelectricity:-

Let us arrange a closed circuit of two metals and maintain the same temperature at all points. We will find that under this condition there will be no current in this circuit due to contact potential jumps because its emf is zero:

$$\xi = \Delta V_{12} + \Delta V_{21} = \frac{kT}{e} \left\{ \frac{n_1}{n_2} - \frac{n_2}{n_1} + \frac{n_2}{n_1} - \frac{n_1}{n_2} \right\} = 0 \quad (3)$$

This result could have been foreseen from the first and second laws of thermodynamics. Indeed, a current does work and therefore a source of energy is required to produce a current. This cannot be the energy of the environment because, according to the second law of thermodynamics, there is no heat exchange between bodies at the same temperature.

The result will be quite different if the temperatures of the junctions are not the same. Assume, for instance, that $T_1 > T_2$. Then the expression for the emf becomes

$$\xi = \Delta V_{12} + \Delta V_{21} = \frac{k}{e} \left\{ \frac{n_1}{n_2} - \frac{n_2}{n_1} \right\} (T_1 - T_2) \quad \text{---(4)}$$

The emf here is evidently not equal to zero, and a thermoelectric current is established in the circuit.

This phenomenon was discovered in 1821 by T. Seebeck (1770-1831).

Eqn(4) can be rewritten as

$$\xi = \alpha (T_1 - T_2) = \alpha \Delta T$$

$$\text{where } \alpha = \frac{k}{e} \left\{ \frac{n_1}{n_2} - \frac{n_2}{n_1} \right\} =$$

T = difference in temperature of the two junctions

ξ = thermoelectromotive force.

Constant characterizing the

The thermoelectromotive force arising from the contact of two metals is very small. Though Eqn was derived by means of quite crude approximations, it can be used for a qualitative estimation of this thermoelectromotive force. Taking $T = 1K$ and concentrations n_1 and n_2 , for instance, from the data in Table. For copper and aluminium. We obtain

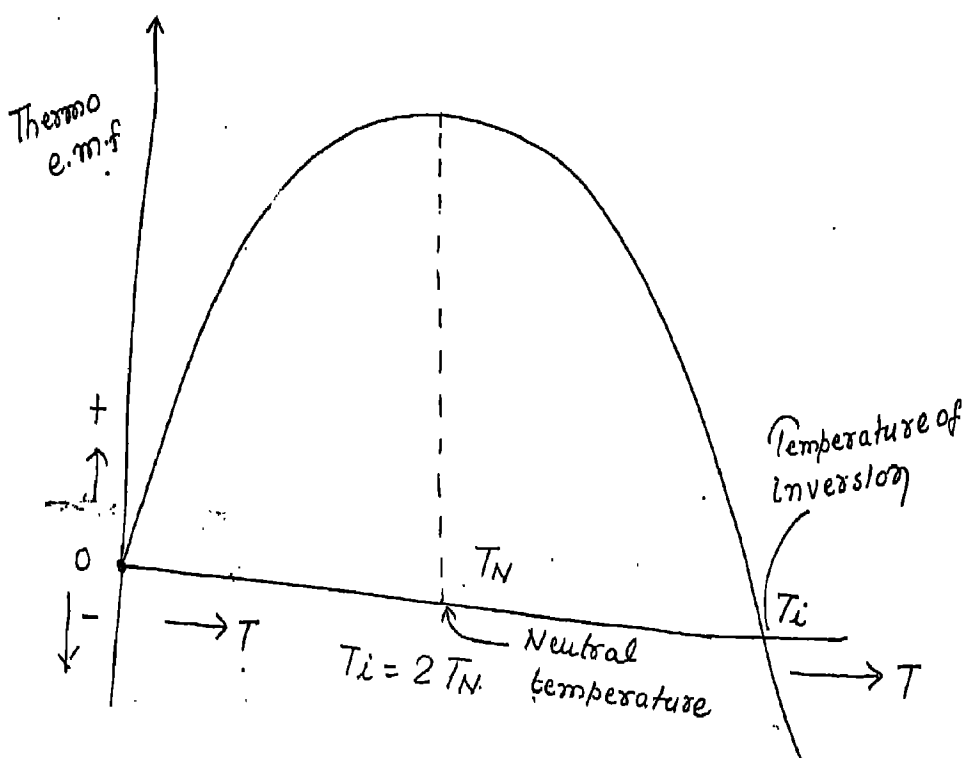
$$\alpha = \frac{k}{e} \left\{ \frac{n_1}{n_2} - \frac{n_2}{n_1} \right\} = \frac{1.38 \times 10^{-23}}{1.61 \times 10^{-19}} \left\{ \frac{21}{11} - \frac{11}{21} \right\} = 1.2 \times 10^{-4} \text{ V/K}$$

= 120 (mu) V/K
= 120 μ V/K

Experimental data for a thermoelectric couple of these metals

is only 1/30 as much: $= 3.4 (\mu\text{V/K}) = 3.4 \mu\text{V/K}$

If we replace one of the metals by a Semiconductor, the thermoelectromotive force should substantially increase because the electron concentrations in metals and semiconductors differs by 4 or 5 orders of magnitude. Eqn. is inapplicable here, even for qualitative calculations, but the fact is confirmed experimentally that a metal semiconductor thermocouple given rise to a much higher thermoelectromotive force than a metal metal one.



- TABLE -

$$m^3/c \quad \left(\frac{1}{\text{Ohm-m}} \right)$$

~~TABLE~~

RH

6

$$n = \frac{1}{e R_H} = \left(\frac{1}{m^3} \right)$$

Aluminium	0.30×10^{-10}	4.08×10^{-7}	20.8×10^{28}
Copper	0.55×10^{-10}	6.41×10^{-7}	11.4×10^{28}
Sodium	2.50×10^{-10}	2.48×10^{-7}	2.50×10^{28}
Lithium	1.70×10^{-10}	1.17×10^{-7}	3.67×10^{28}
Zinc Oxide	1.6×10^{-5}	3.0×10^2	3.9×10^{28}

Concentration of atoms Average number of free electrons per atom Electron mobility

$$n_A = \frac{\rho N_A}{A} \left(\frac{1}{m^3} \right)$$

$$= n/n_A$$

$$b = \frac{1}{e R_H} \quad \left(\frac{m^2}{V-s} \right)$$

Aluminium	6.03×10^{28}	3.46	1.2×10^{-3}
Copper	8.49×10^{28}	1.34	3.5×10^{-3}
Lithium	4.60×10^{28}	0.80	2.00×10^{-3}
Sodium	2.54×10^{28}	0.99	6.2×10^{-3}
Zinc Oxide	$= 4 \times 10^{28}$	$\approx 10^{-5}$	4.8×10^{-3}

Can you explain the curve with the Eqn... (4)

$$\xi = \frac{K}{e} \left\{ \frac{n_1}{n_2} - \frac{n_2}{n_1} \right\} (T_1 - T_2)$$

CHAPTER III

3.1 Formation of Energy bands in Crystals

Splitting of Energy levels in a crystal :-

Take N atoms of substance and arrange them at a sufficiently large distance from each other but in such a way that this arrangement reproduces the crystalline structure of the material, since the separation between the atoms is large, we can ignore their interaction and consider them free. In each of these atoms, there are degenerate levels with degeneracies equal to the number of differently oriented similar orbits in corresponding subshells. (States described by different sets of quantum numbers but having the same energy are called degenerate. The levels are degenerate while the atoms are in free state. If however, the atoms are placed in a strong electric or magnetic field, the degeneracy is partially or completely removed. The process in which previously indistinguishable (from point of view of energy) degenerate levels become distinguishable is called the removal of degeneracy.)

Let us now start bringing the atoms closer as shown in Figure ^{3.1, 3.3, 3.4}-----, they begin to experience the influence of their approaching neighbours, which is similar to the influence of an external electric field. The smaller the separation between the atoms, the stronger the interaction between them. Owing to this interaction, degeneracy of energy levels characterizing

the free atoms is removed; each degenerate level splits into $(2l+1)$ non-degenerate levels. All the atoms in a crystal generally exist under the same conditions (except for those which form the external

boundary of the crystal). It could be seen therefore that each atom should contribute the same set of non-degenerate sublevels into the energy spectrum that characterized the crystal as a whole viz, one $1s$ sublevel, three $2p$ -sublevels, five $3d$ -sublevels, & so on. Each sublevel may contain two electrons with opposite spins. Although this splitting actually occurs the corresponding sublevels obtained from similar atomic levels differs from each other in energy, some of them are higher in the energy spectrum of the crystal than the initial levels of the individual atoms, while others lie somewhat lower. This difference can be explained by Pauli's exclusion principle generalized for entire crystal as single entity. According to this principle, no two non-degenerate sublevels in a crystal may have the same energy. Therefore, when the crystal is formed, each energy level spreads in to an energy band consisting of $N(2l+1)$ non-degenerate sublevels differing in energy. For example the $1s$ level spreads into $1s$ -band consisting of N sublevels which may contain $2N$ electrons, the $2p$ sublevel spreads into $2p$ sub band consisting of $3N$ sublevels which may contain $6N$ electrons, and so on.

The formation of energy band in a crystal from discrete energy levels of individual atoms is shown in Fig.2.

The shorter the distance, the stronger the effect of the neighbouring atoms and the more the levels are "smeared". The energy spectrum of the crystal is determined by the smearing of the levels corresponding

to the interatomic distance as typical of a given crystal.

The degree of smearing of levels depends on their depth in an atom. The inner electrons are strongly coupled to their nuclei and are screened from external effects by the outer electron shells. Therefore the corresponding energy levels are weakly smeared. Naturally, the electrons in the outershell are most strongly affected by the field of the crystal lattice, and the energy levels corresponding to them are smeared the most. It should be noted that smearing of levels into energy band does not depend on whether there are electrons on these levels or whether they are empty. In latter case, the smearing of levels indicates the broadening the range of possible energies which the electron may acquire in the crystal.

3.2 Allowed and Forbidden Bands :-

There is an entire band of allowed energy values corresponding to each allowed energy levels in a crystal, i.e there is an allowed band. Allowed bands alternate with the bands of forbidden energy, or forbidden bands. Electrons in a pure crystal cannot have an energy lying in the forbidden bands. The higher the allowed atomic level on the energy scale, the more the corresponding band is smeared. As the energy increases, the forbidden bands become narrower.

The separation of sublevels in an allowed band is very small. In real crystals ranging from 1 to 100 cm^3 in size, the sublevels are separated by 10^{-22} to 10^{-24} eV.

3

This difference in energy levels is so small that the bands are considered to be continuous. Nevertheless, the fact that sublevels in the bands are discrete and the number of sublevels in the band is always finite plays a decisive role in crystal physics. Since depending on the filling of bands by electrons, all solids can be divided into conductors, semiconductors and insulators.

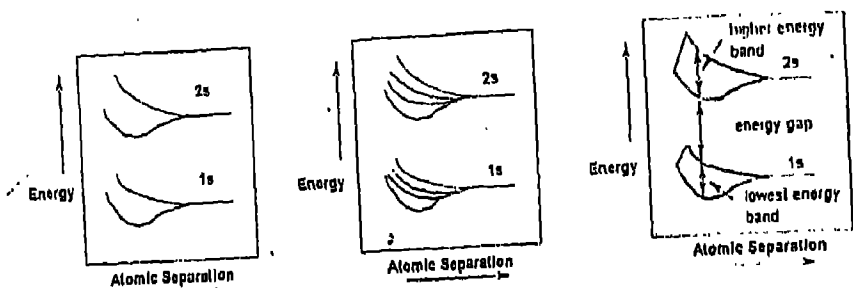
3.3 Formation of Energy bands :-

As the isolated atoms are brought together to form a solid, various interactions occur between neighboring atoms. The forces of attraction and repulsion between atoms will find a balance at the proper interatomic spacing for the crystal. In this process important changes occur in the electron energy level configurations, and these changes result in the varied electrical properties of solids.

Qualitatively, when atoms are brought together the application of Pauli's exclusion principle is important. When the two atoms are completely isolated from each other so that there is no interaction of electron wave function (cloud) between them, they can have identical electronic structures. As the spacing between the two atoms becomes smaller, however, electron wave functions begin to overlap. The exclusion principle dictates that no two electrons in a given interacting system may have the same quantum state; thus there must be a splitting of the discrete levels of the isolated atoms into new levels belonging to the pair rather than to individual atoms.

In a solid, many atoms are brought together,

so that the split energy levels form essentially continuous bands of energies. Figure 3.5(a&b) illustrates the imaginary formation of a diamond crystal from isolated carbon atoms. Each isolated carbon atom has an electronic structure $1s^2 2s^2 2p^2$ in the ground state. Each atom has available two 1S states, two 2S states and six 2p states, and higher states. If we consider N atoms, there will be $2N, 2N,$ and $6N$ states of type 1S, 2S, and 2p, respectively. As the interatomic spacing is decreases, these energy levels split into bands, beginning with the outer ($n=2$) shell. As the "2S" and "2p" bands grow, they merge in to single band composed of mixture of energy levels. This band of "2S-2p" level contain $8N$ available states. As the distance between atoms approaches the equilibrium interatomic spacing of diamond, this band splits into two bands separated by an energy interval (Gap) E_g . The upper band (called the conduction band) contains $4N$ states, as does the lower (valence) band. Thus, apart from low lying and tightly bound "1S" levels, the diamond structure (crystal) has two bands of available energy levels separated by an energy gap E_g wide, which contains no allowed energy levels for electrons to occupy. This gap is sometimes called a "forbidden band, since in a perfect crystal it contains no electron states (imperfections, impurities, defect.....in a crystal will have states in the energy gap). Let us count electrons. The lower "1S" band is filled with the $2N$ electrons which originally reside in the collective 1S states of the isolated atoms. However, there were $4N$ electrons in the original $n=2$ shells ($2N$ in 2S



The splitting of 1s and 2s atomic energy levels.

(a) when 2 hydrogen atoms approach each other, there are two energy states splitted in each 1s and 2s levels of

(b) when 4 hydrogen atoms approach each other, there are four energy states splitted in each 1s and 2s levels of each atom

Fig 3.3

The formation of energy bands.

When many hydrogen atoms come together to form a solid, the nearby energy states at each of the original atomic levels form an energy band

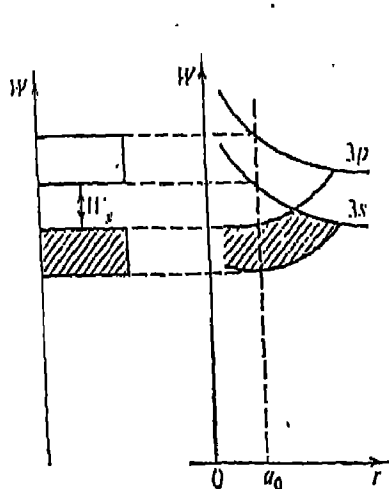
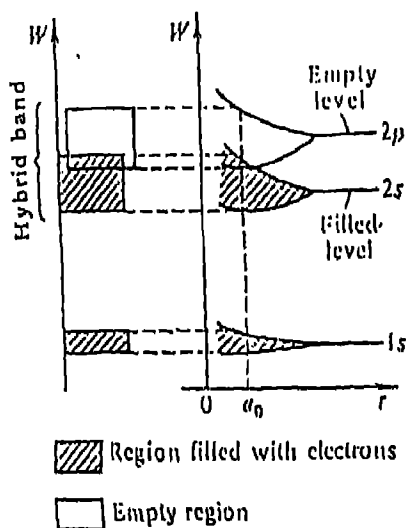
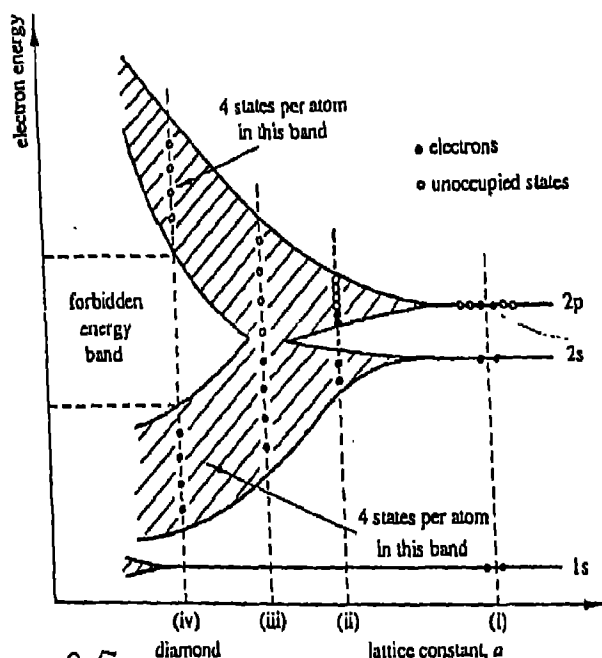


Fig 3.4



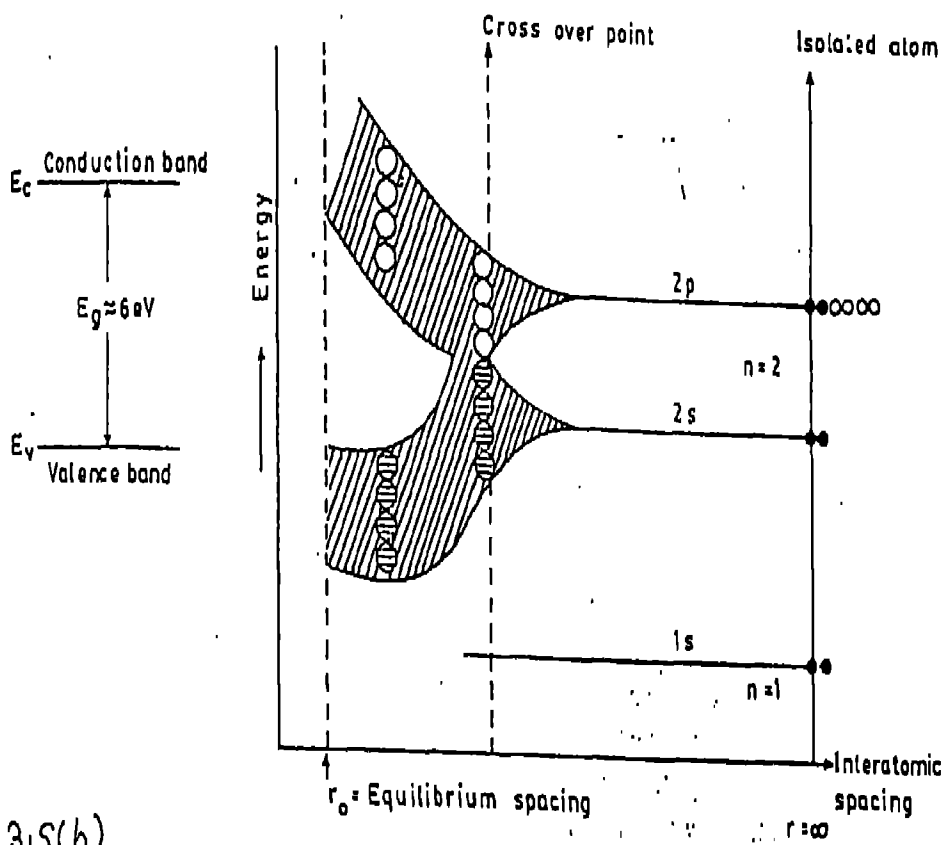
Region filled with electrons

Empty region



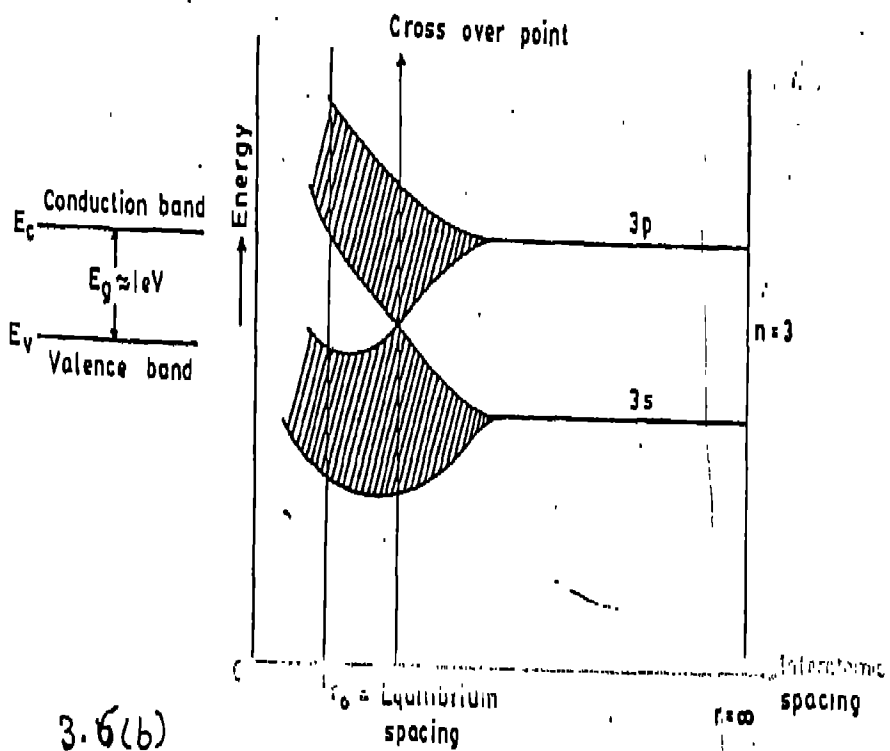
3.5

Fig. Energy bands for carbon with varying interatomic spacing.



3.5(b)

Fig. 3.5 The bands arising from the $1s$, $2s$ and $2p$ atomic states of carbon (diamond) as a function of interatomic distance



3.6(b)

Fig. 3.6 The bands arising from the $3s$ and $3p$ states of silicon as a function of interatomic distance

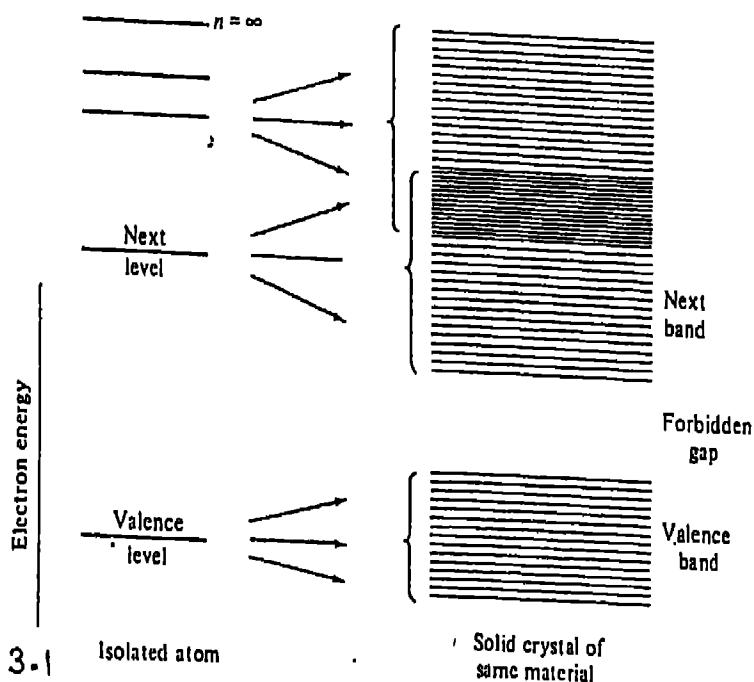


FIGURE 3.1 The discrete energy levels of the isolated atoms (left) merge into bands of energy (right) when a crystal is formed. The arrangement of the energy bands is a characteristic of the crystal. (Adapted from J. N. Shive, *Physics of Solid State Electronics*, Charles E. Merrill Publishing Company, 1966.)

* The conduction band is a band or part of a band that lies above the outermost occupied band at absolute zero.

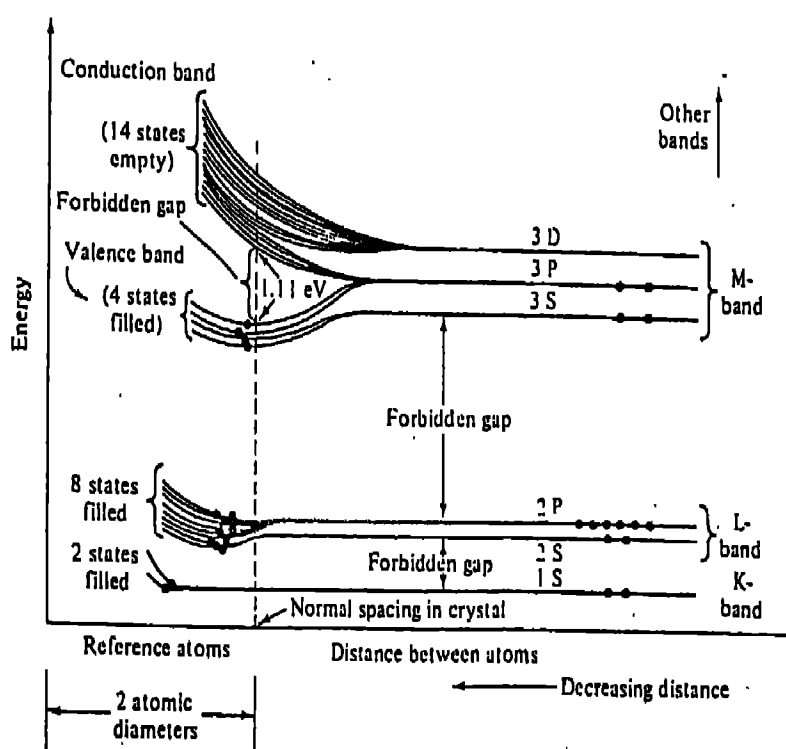


FIGURE 3.2 Band spreading and splitting as a function of atomic spacing for silicon. This figure shows how the orbitals of one atom are affected by the interaction with the orbitals of a second atom as the first atom is moved from right to left. The second atom is stationary at the reference.

1

2

FORMATION OF BANDS IN A SOLIDS:- When atoms are bound together in a crystal, two important effects are produced on the energy levels of the various atoms. First, the individual levels are shifted to produce energy bands instead of discrete energy levels. A band is made up of many energy states so close together that it would be impractical to try to distinguish individual states. At these high energy levels, these allowed energy bands may cover a range of one electron volt or more. The second effect is band splitting. As the atoms move close together, some of the individual states may move to higher energy states and some to lower ones. Band spreading and band splitting as a function of the distance between the atoms is shown in the figure

The electrical characteristics of a crystal are determined by the manner in which the energy bands spread, split and overlap. The following example illustrates how the levels of the isolated atoms are modified by bringing atoms close together.

EXAMPLE:-*How do the energy levels in an atom of silicon change as the atom moves close to other atoms of the same type?*

We know that silicon has 14 electrons distributed in the various levels

K(2), L(8), M(4), thus K and L bands filled to its full capacity ($2n^2$); and has four electrons in the M band ($n=3$) appear in the three level, two in the 3S-level, six in the 3P-level and ten in the 3D-level. Two of the four valence electrons fill in the two 3S-levels and the other two are in the lower 3P-levels.

If the two atoms are many atomic diameters apart, the energy bands are very narrow, as shown in the figure. When the separation distance is two or three atomic diameters, the valence band energy level spread. The important point here is that the two states in the 3p-level containing the two electrons move DOWN while the other four empty states move UP. At the normal atomic spacing found in silicon crystal, an energy gap or the forbidden gap of approximately 1.11 eV exists between an energy state containing a valence electron and the next lowest unfilled energy states. This energy gap is caused by the band splitting effect.

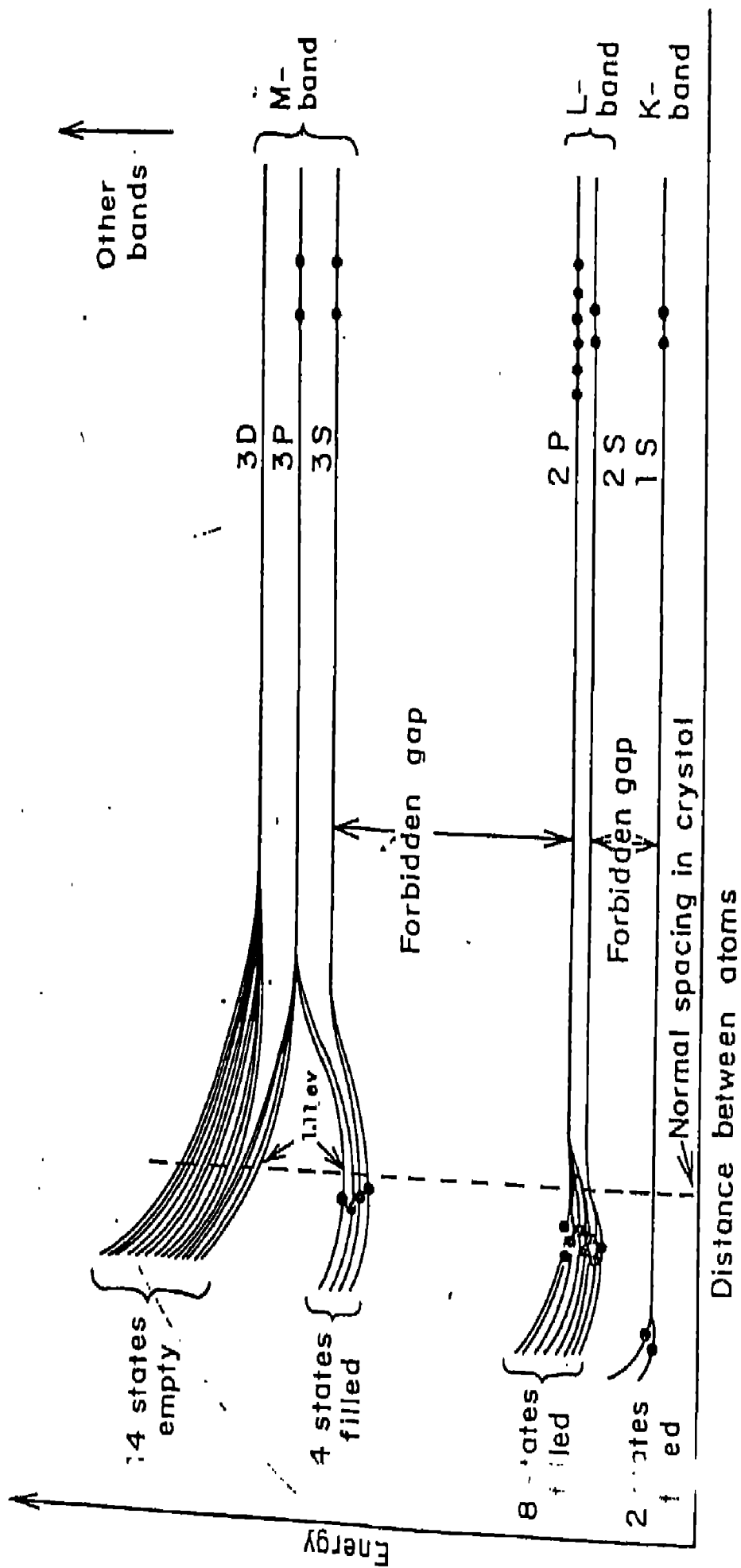


Fig. 1.2. Band spreading and splitting as a function of the atomic spacing for silicon. Note that the lower bands do not spread at normal spacing (not to scale).

SEMICONDUCTORS

Preview

Introduction :-

About 70% of the ^hundred or so known elements are metals. Most of the rest are non-metals, i.e. do not contain free electrons when packed together to make solids. The metals and non-metals are grouped together at opposite ends of the periodic table of elements- a group of about ^{12 (Twelve) fig 4.2} elements along the boundary are semiconductors. They have some free electrons when packed together, but nothing like one per atom which is the norm for metals. Furthermore, the number of free electrons rises drastically (exponentially) with temperature, lowering resistivity of the semiconductor.

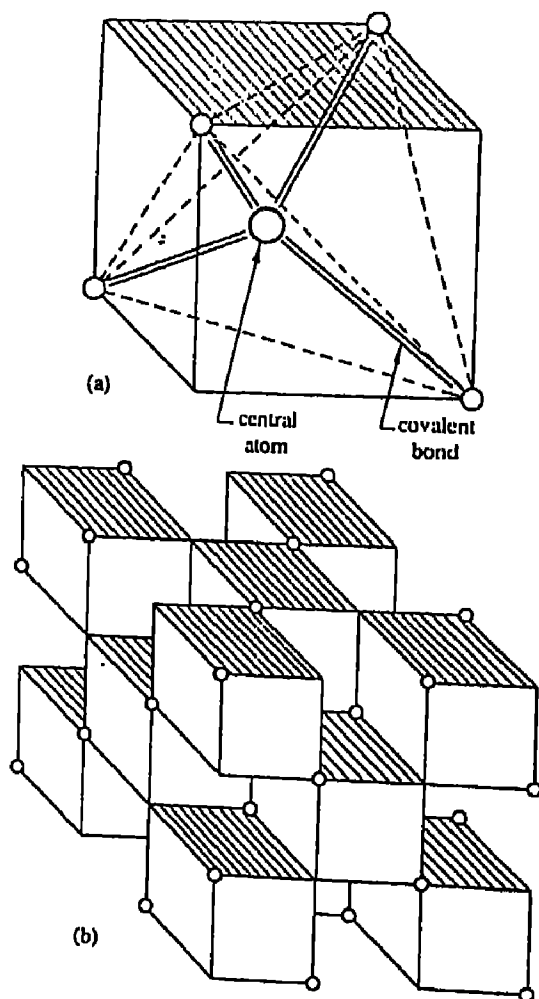
Semiconductors :-

The name has been applied to a large number of chemical elements and compounds of which the most important are germanium and Silicon, ^aBesides these there are many compounds so called III-V compounds such as Gallium arsenide, indium antimonide, and gallium phosphide, indium phosphide etc.

We will define semiconductor as:

Semiconductors are materials the conductivity of which at room temperature ranges between 10^{-8} and 10^6 S m^{-1}

and depends strongly on the nature and amount of impurities on the structure of the material and on the ambient; temperature, illumination, electric and magnetic fields



4.1

Fig. 4.1 (a) A unit cell of a tetravalent atom; (b) packing of such atoms to form a crystal with a diamond structure.

Valency group	IIIA	IVA	VA	VIA	VIIA
	B 2p Boron	C 2p ² Carbon			
	Al 3p Aluminium	Si 3p ² Silicon	P 3p ³ Phosphorus	S 3p ⁴ Sulphur	
	Ga 4p Gallium	Ge 4p ² Germanium	As 4p ³ Arsenic	Se 4p ⁴ Selenium	
	In 5p Indium	Sn 5p ² Tin	Sb 5p ³ Antimony	Te 5p ⁴ Tellurium	I 5p ⁵ Iodine
			Bi 6p ³ Bismuth		

Key :

Chemical symbol	Number of electrons in subshell	Atomic number
(Outer subshell)		
Name of the element		

4.2

Fig. 4.2 Part of the periodic table of elements showing those elements of principal interest for application to semiconductor devices.

The most common semiconductors are the elemental semiconductors silicon and germanium. Other common elemental semiconductors are diamond(carbon), graytin, tellurium, selenium and boron. Closely related to the group IV semiconductors diamond, silicon, germanium and graytin are the III-V compounds formed from elements in the third and fifth columns of the periodic table, such as InSb, InAs, GaAs, GaP, and GaSb. Another important class of inorganic semiconductors is the II-VI compounds, formed from elements in the second and sixth columns of the periodic table such as CdS, CdSe, CdTe, ZnSe, ZnTe, HgS, HgSe, and HgTe. Many other varieties of compound semiconductors are found, some of the more common varieties being the IV-IV compound SiC, IV-VI compounds PbS, PbSe and PbTe, SnTe, SnSe, $Pb_x Sn_{1-x} Te$, $Pb_x Sn_{1-x} Se$, GeTe and the oxides MnO, NiO, SiO₂, SnO₂, GeO₂ of great interest are the more complex compounds and Solid solutions which include substances of the $A^x B_1^{8-x} B_2^{8-x}$; $A_1^x A_2^x B^{8-x}$; $A_1^x A_2^x B_1^{8-x}$

type for examples; GaAs P, In Ga Sb or Zn CdSe Te may serves as examples of Solid Solutions:

Pb Sn Te; $Pb_{0.1} Sn_{0.9} Te$; $Pb_{0.2} Sn_{0.8} Te$; etc.

Many compounds can be formed by elements from three different columns, as, for instance, mercury indium telluride ($Hg In_2 Te_4$), a II-III-VI compound. They also can be formed by elements from two columns, such as aluminium gallium arsenide ($Al_x Ga_{1-x} As$), which is a ternary III-V compound, where both Al and Ga are from column III and subscript x is related to the composition of the

Semiconducting material :-

The current in electronic conductors is carried by electrons only, there is no transport of matter, and devices made from electronic semiconductors can operate for long period of time.

12 elements belongs to the semiconductor group :

boron(B), carbon(C); Silicon (Si), phosphorus (P), Sulphur (S) germanium(Ge), arsenic As, Selenium (Se),

greytin (Sn) antimony (Sb), tellurium (Te), Iodine(I),

figure 4.2 shows the position of the semiconductor among the other elements of Mendeleev's periodic table.

Most important atomic semiconductors are at present Silicon and Germanium.

Many binary compounds of the $A^X B^{8-X}$ type (when A is the element of the group X and B-the element of the group(8-X) exhibit semiconductive properties. Type $A^I B^{VI}$ includes AgCl, CuBr, KBr, LiF, etc. As yet, they are not in great use as semiconductive materials.

Type $A^{II} B^{VII}$ includes Sulphides, tellurides and selenides and oxides of group II metals. The best known is HgSe, etc. They are being used widely now and in future will be put to use. Amongst the most important present day semiconductive compounds are the substances of the $A^{III} B^V$ type. They includes antimonides; arsenides, phosphides, and nitrides of the substance group III of group (III) (aluminium, gallium, indium, and boron).

4.4 Table 4.3 Crystal Structure and Energy Gaps of I_B-VII_A Compounds*

Element	F	Cl	Br	I
Cu	Z	Z	Z 3 eV	Z'
Ag	R	R	R	W Z 2.8 eV
Au	—	—	—	—

* Ionic conductors; Z = zinc blende, W = wurtzite, R = rhombohedral.

4.5 Table 4.3 Energy Gaps of II_A-VI_A Compounds*

Element	O	S	Se	Te
Be	—	—	—	—
Mg	7 eV	—	5.6 eV	4.7 eV
Ca	5 eV	5.4 eV	5.0 eV	4.3 eV
Sr	5 eV	4.8 eV	4.6 eV	4.0 eV
Ba	4.8 eV	3.4 eV	3.7 eV	3.4 eV

* Insulators.

4.6 Table 4.3 Crystal Structure and Energy Gaps of IV_A-VI_A Compounds

Element	O	S	Se	Te
C	Gas	—	—	—
Si	7.2 eV	—	—	—
Ge	—	—	2 eV	1.1 eV
Sn	—	1.3 eV	0.8 eV	Rs* 0.2 eV
Pb	—	Rst 0.37 eV	Rst 0.25 eV	Rst 0.32 eV

* SnO₂ (3.5 eV).

† Rock salt.

4.2
Table 4.2 Crystal Structure and Energy Gaps of III_A-V_A Compounds*

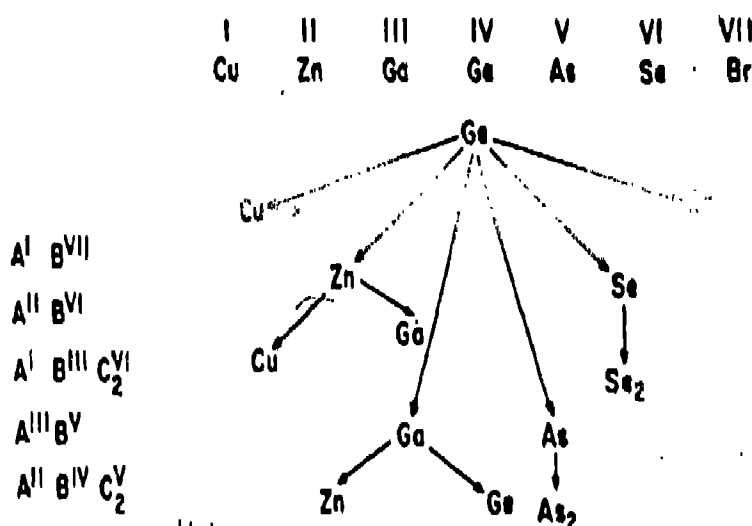
Element	N	P	As	Sb
B	Z† 5.0 eV	Z 4.2 eV	Z 3.0 eV	Z 2.8 eV
Al	W 4.0 eV	Z 3.1 eV	Z 2.2 eV	Z 1.5 eV
Ga	W 3.3 eV	Z 2.2 eV	Z 1.4 eV	Z 0.71 eV
In	W 2.5 eV	Z 1.2 eV	Z 0.35 eV	Z 0.18 eV

* More than sixteen separate compounds represented: Z = zinc blende, W = wurtzite, R = rhombohedral, X = other crystal structure.
† BN, BN₂, BN₃.

4.3
Table 4.3 Crystal Structure and Energy Gaps of II_B-VI_A Compounds*

Element	O	S	Se	Te
Zn	W 3.3 eV	Z 3.8 eV	Z 2.8 eV	W 2.2 eV
Cd	R 2.0 eV	W 2.5 eV	W 1.7 eV	Z 1.4 eV
Hg	X —	X 0.97 eV	Z 0.32 eV	Z ≈ 0

* More than eleven materials represented: Z = zinc blende, W = wurtzite, R = rhombohedral, X = other crystal structure.



4.4
Fig. 4.4 Isoelectronic chalcopyrite compounds

4.7
Table 4.7 Energy Gaps of A_2B^V Compounds

	C	Si	Ge	Sn	Pb
Be ₂	—	—	—	—	—
Mg ₂	—	0.7 eV	0.6 eV	0.3 eV	Metal*
Ca ₂	—	1.8 eV	—	0.9 eV	0.46 eV
Sr ₂	—	—	—	—	—
Ba ₂	—	—	—	—	—

* Negative gap

4.8
Table 4.8 Energy Gaps of A_2B^V Compounds

	O	S	Se	Te
Cu ₂	2.0 eV	1.8 eV	1.3 eV	1.0 eV
Ag ₂	—	0.9 eV	—	0.8 eV
Au ₂	—	—	—	—

4.9
Table 4.9 Energy Gaps of $A_2B_3^V$ Compounds

	O ₃	S ₃	Se ₃	Te ₃
B ₂	—	—	—	—
Al ₂	7.5 eV	4.1 eV	3.1 eV	2.5 eV
Ga ₂	4.4 eV	2.5 eV	1.9 eV	1.0 eV
In ₂	3.5 eV	2.0 eV	1.2 eV	1.0 eV

4.10
Table 4.10 Energy Gaps of $A_2B_3^V$ Compounds*

	O ₃	S ₃	Se ₃	Te ₃
N ₂	—	—	—	—
P ₂	—	—	—	—
As ₂	4.0 eV	2.5 eV	1.7 eV	1.1 eV
Sb ₂	4.2 eV	1.5 eV	1.2 eV	0.3 eV
Bi ₂	3.2 eV	1.3 eV	0.35 eV	0.15 eV

* Thermoelectric materials.

two elements from 100 percent Al($x=1$) to 100 percent Ga($x=0$) pure silicon is the most important material for integrated circuit application, and III-V binary and ternary compounds are most significant for light emission. Another class of semiconductors is the organic semiconductors common examples being anthracene, tetracene, free radicals, such as -diphenyl-B-picrylhydrazyl, biologically interesting material such as the phthalocyanines, and various organic dyes.

Certain classes of semiconductors also possess other interesting properties. For example, the europium chalcogenides form a family of magnetic semiconductors, with EuO, EuS, and EuSe undergo a ferromagnetic phase transition, while EuTe becomes antiferromagnetic below a Neel temperature of 9.8 K. Magnetic semiconductors are of particular interest because of close coupling between the electrical and magnetic properties, such as electrical conductivity and the magnetic susceptibility. Some semiconductors have also been undergo a superconducting phase transition, as for example GaTe and SnTe for carrier concentration $\sim 10^{22} / \text{cm}^3$ and transition temperature 0.3 K. Although most of the common semiconductors utilizes crystalline materials, semiconductors are also found in the liquid and amorphous states. Of special interest is the fact that the electrical conductivity of an amorphous semiconductor tends to much lower than that of its crystalline counterpart; the opposite situation prevails for amorphous and crystalline metals. Common semiconductors like silicon and Germanium have been prepared in the amorphous state, although the major

emphasis in recent years has been given to the amorphous chalcogenide glasses containing tellurium and selenium along with a host of other elements; these glasses have been utilized for switching and memory devices.

Physical properties :-

Semiconductors tend to be hard and brittle and become ductile only at high temperatures. The hardness of semiconductors like diamond and SiC is utilized in the manufacture of industrial abrasives. Because of this hardness, high quality optical surfaces on semiconductors can be achieved using lapping and etching techniques. The structural formula the largest family of semiconducting binary (AB) compound is $A^N B^{8-N}$; that is, there are eight electrons per A-B atom pair, N being the group number in the periodic table and 8-N, the coordination number. The crystal structure include diamond, the zinc blends, and the wurtzite lattices.

Also included in Table 1 is a member of another family of semiconducting binary compounds $PbTe, PbSe, PbS$ called lead chalcogenides or lead salts, and other IV-VI compounds $SnTe, etc.$ These are used as detectors of

infrared radiation and as photocell material. They have the structural formula $A^N B^{10-N}$, so that $A=Pb$ and hence $N=4$, the coordination number is $10-N=6$ as in rock salt or NaCl structure. They are called the

plastic semiconductors, by which is meant that the interatomic bonds in the crystal are predominantly ionic in character and are mediated by central electrostatic forces.

POINTS TO REMEMBER :- Semiconductors

1. The equilibrium number of electron hole pair in pure silicon (intrinsic) at room temperature is only about $\simeq 10^{10}$ EHP/cm³ where EHP means (electron hole pair) compared to the silicon atom density of more than 10^{22} atoms/cm³. Thus a few electrons in the conduction band are free to move about via the many available empty state.
However there are $\simeq 10^{13}$ EHP/cm³ in Germanium at room temperature.
2. One cubic millimeter of Ge (which is about the size of a pinhead) contains about 5×10^{19} atoms. So if only one part in million of some impurity were present, there would be in that tiny piece of Ge 50,000,000,000,00 atoms of impurity (5×10^{12}).
3. In Si for example the intrinsic carrier concentration $n_i \simeq 10^{10}$ cm⁻³ at room temperature. If we doped with 10^{15} Sb atoms/cc the conduction electron concentration changes by five order of magnitude.
The resistivity of Si changes from 2×10^5 to 5 (Ohm, cm) with this doping.
4. For Si at 300°K $n_i = p_i = 10^{10}$ cm⁻³ where as the density of available states E_v and E_c are of the order $\simeq 10^{19}$ cm⁻³

5. Band gap (energy gap) (varies) decreases with increase in temperature for Si $E_g = 1.11 \text{ eV}$ at 300°K ; $E_g = 1.16 \text{ eV}$ at 0°K

$$E_g = E_g(0) - E_g T$$

Where $E_g(0)$ is the width of energy gap at absolute zero of temperature, $E_g(\text{V}/^\circ\text{C})$ is the temperature sensitivity and T is absolute temperature $^\circ\text{K}$.

For silicon $E_g(0) = 1.21 \text{ eV}$, $E_g = 3 \times 10^{-4} \text{ eV}/^\circ\text{C}$

and hence the room temperature value of E_g is near 1.12 eV .

6. Let n be the number of atoms per molecule then

Molecular weight = $n \times \text{atomic weight}$

$$\text{Number of moles}/\text{cm}^3 = \frac{P}{n \times \text{atomic weight}}$$

$$\text{Number of molecules}/\text{cm}^3 = \frac{A P}{n \times \text{atomic weight}}$$

$$\begin{aligned} \text{Number of atoms}/\text{cm}^3 &= \frac{n A P}{n \times \text{atomic weight}} \\ &= \frac{A P}{\text{atomic weight}} \end{aligned}$$

Example :-

For Silicon $P = 2.33 \text{ gm}/\text{cm}^3$
Atomic weight 28.08 gm

$$\text{density of atoms} = \frac{6.02 \times 10^{23} \times 2.33}{28.08}$$

$$= 5 \times 10^{22} \text{ cm}^{-3} \quad 10^{23}/\text{cc}$$

For Germanium

$$P = 5.32$$

$$\text{density} = \frac{6.02 \times 10^{23} \times 5.32}{72.6}$$

$$= 4.41 \times 10^{22} \text{ cm}^{-3} / \text{ or } 10^{22} / \text{cc}$$

7. Care must be taken to use consistent units in the calculation. For ex. if an energy such as E_g is expressed in (e V); it should be multiplied by $Q(1.6 \times 10^{-19} \text{ C})$ to convert to joules if K is in J/oK. alternately, E_g can be kept in V and the value of K in eV/oK. can be used.
8. For extrinsic conduction to exceed intorinsic conduction, the donor atom concentration N_d or the acceptor concentration N_a should exceed the intrinsic carrier concentration $n_i = p_i$
 In practical manufactur of extrinsic semiconductor N_a or N_d is always many times, n_i or p_i for example, in case of Ge which has $n_i = p_i = 10^{13} \text{ cm}^{-3}$ at room temperature N_d and N_a may range anywhere between 10^{15} and 10^{18} cm^{-3} , which is 10^2 to 10^5 times the intrinsic carrier concentration.
9. In semiconductor containing substantially only one type of current carrier, it is impossible to increase the total carrier concentration by injecting carriers of the same type; however, such increase can be produced by injecting the opposite type. Since the space charge of the latter can be neutralize by increased concentration of the type normally present.

If $N_d \gg n_i$, we may neglect intrinsic carrier conc (that is that of electrons) and then $n_h^* \approx N_d$

Taking n-type germanium as an example n_n may be about 10^{-16} cm^{-3} clearly, as compared with this figure one must not consider the intrinsic carrier concentration which is $n_i = 10^{13} \text{ cm}^{-8}$ or by a factor of 1000 smaller.

Effect of temperature :-

The minority carrier conc in an extrinsic Semiconductor decreases in the same proportion as the majority carrier concentration increases. Thus if i-type germanium has $n_i = p_i = 10^{13} \text{ cm}^{-3}$, and doping it with a donor impurity increase the fig. 1000 fold to $n_n = 10^{16} \text{ cm}^{-3}$ the minority carriers (holes) concentration will fall to 1/1000th of its previous value to become $p_n = 10^{10} \text{ cm}^{-3}$, which is one millionth of the majority carrier concentration.

The explanation is that when the conduction electron concentration is increased 1000-fold due to contribution from donor atoms, the lower energy levels in the conduction band are filled full, and electrons from the valence band can now jump only to the higher energy levels of the conduction band. For this jump to occur, however, the electron must have a greater energy than they do in an intrinsic semiconductor, doing this. The number of holes in the valence band then decreases in about the same sizeable proportion. It has been found that n-type extrinsic semiconductor always satisfy the following equality:

$$n_n P_n = n_i = n_i^2 = p_i^2$$

In our example

$$10^{16} \times 10^{10} = (10^{13})^2 = 10^{26}$$

Everything said about n type semiconductors fully applies to p-type semiconductors.

In then $N_a \gg p_i$ and we may deem that $P_p \approx N_a$.

For example, in the case of p-type semiconductors

(germanium) the figure may be $P_p = 10^{16}$ and $n_p = 10^{10} \text{ cm}^{-3}$

for p-type semiconductors, the equality $P_p n_p = n_i p_i = n_i^2 = p_i^2$

always holds (Mass action and Conservation)

- *. Even minute amounts of an impurity can drastically change both the type of conduction and the magnitude of conductivity of a semiconductors. Indeed as many as 4.4×10^{22} germanium atoms enclosed in every cubic centimeter of the material, as impurity concentration of 10^{16} cm^{-3} will amount to adding only one impurity atom to the four-odd million germanium atoms. That is, the impurity will account for as little as $10^{-4}\%$ of the total material. Never the less, the majority carrier concentration is increased 1000-fold and the conductivity is improved in the same proportion.

The manufacture of semiconductors carrying such negligible and closely controlled amounts of an impurity is a very sophisticated process.

Table 8.1 Electrical Properties and Band Parameters of Some Common Semiconductors. [After J. L. Moll, "Physics of Semiconductors," McGraw-Hill Book Company, New York, 1964, p. 70.]

Semi-conductor	Energy gap, e_v		Mobility, $cm^2/volt\text{-}sec$ ($T = 300^\circ K$)		Mobility variation $\mu \propto T^{-n}$		Band structure ^b	Effective mass m/m_0		Dielectric constant ϵ
	300°K	0°K	Electrons	Holes	Electrons	Holes		Electrons	Holes	
Ge	0.67	0.75	3,950 (3,900) ^d	3,400 (1,900) ^d	1.66	2.33	A	$m_{\parallel} = 1.6$ $m_{\perp} = 0.082$	0.3, 0.04 ^e	16
Si	1.106	1.153	1,900 (1,350) ^d	425 (480) ^d	2.5	2.7	B	$m_{\parallel} = 0.97$ $m_{\perp} = 0.1\epsilon$	0.5, 0.16 ^e	12
InSb ^f	0.16	0.26	78,000	750	1.6	2.1	C	0.013	0.6	17
InAs ^f	0.33	0.46	33,000	460	1.2	2.3	C	0.02	0.41	14.5
InP ^f	1.29	1.34	14,600	150	2.0	2.4	C	0.07	0.4	14
GaSb ^f	0.67	0.80	4,000	1,400	2.0	0.9	C	0.047	0.5	15
GaAs ^f	1.39	1.58	8,500	400	1.0	2.1	C	0.072	0.5	12.5
GaP ^f	2.24	2.40	110	75	1.5	1.5	B			10

^a The values of mobility are those obtained in the purest and most perfect material available to date. In most circumstances the actual mobilities are less than the value listed.

^b A: germanium-like; conduction-band minimum in $\langle 111 \rangle$ direction; valence-band maximum at $\langle 000 \rangle$.

B: silicon-like: conduction-band minimum in $\langle 100 \rangle$ direction; valence-band maximum at $\langle 000 \rangle$.
C: GaAs-like: conduction-band minimum at $\langle 000 \rangle$; valence band consists of light-hole band with maximum at $k = 0$ and heavy-hole bands with maxima near $k = 0$ (see figure).

There are significant variations among the various semiconductors in details of the band structure beyond this A, B, C classification.

^c E. M. Conwell, Properties of Silicon and Germanium, *Proc. IRE*, 46: 6 (June, 1958), has a fairly comprehensive discussion of the properties of silicon and germanium.

^d The numbers in parentheses are drift mobilities.

^e The heavy- and light-hole masses are both given.

^f C. Hilsum and A. C. Rose-Innes, "Semiconducting III-V Compounds," Pergamon Press, New York, 1961, list the properties of the III-V compounds and discuss the details of the band structure, etc., that must be neglected in a listing such as this.

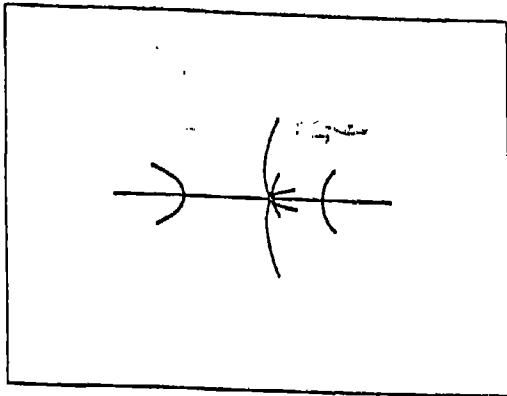


TABLE 1.1

Some properties of silicon and germanium, and impurities commonly used to control their electrical conductivities.

Element	Number of Valence Electrons	Atomic Number	Radius in Crystal (Angstroms)	Function	Majority Free Carrier	Electron Volts		Conductivity Type Created
						Ionization Energy to Produce Free Carrier	in Ge†	
Boron (B)	3	5	0.81	Acceptor	Hole	0.0104	0.045	p-type
Aluminum (Al)	3	13	1.26	Acceptor	Hole	0.0102	0.057	p-type
Gallium (Ga)	3	31	1.26	Acceptor	Hole	0.0108	0.065	p-type
Indium (In)	3	49	1.44	Acceptor	Hole	0.0112	0.16	p-type
Tin (Sn)	4	50	1.40	Neutral				
Phosphorus (P)	5	15	1.13	Donor	Electron	0.0120	0.044	n-type
Arsenic (As)	5	33	1.18	Donor	Electron	0.0127	0.049	n-type
Antimony (Sb)	5	51	1.36	Donor	Electron	0.0096	0.039	n-type
Silicon (Si)	4	14	1.17	Host	Equal	1.205	$2.8 \times 10^{-4} T(^{\circ}K)$	intrinsic
Germanium (Ge)	4	32	1.22	Host	Equal	0.782	$3.9 \times 10^{-4} T(^{\circ}K)$	intrinsic

† R. A. Smith, *Semiconductors*, Cambridge University Press, 1959.

† E. M. Conwell, *Proc. IRE*, 46 (June 1958), pp. 1281-1300.

APPENDIX III. PROPERTIES OF SEMICONDUCTOR MATERIALS

	E_g (eV)	μ_n (cm ² /V-sec)	Hall mobility		ρ (Ω -cm)	i indirect	Doping	Lattice	a		Density (g/cm ³)	Melting point (°C)
			μ_p (cm ² /V-sec)	resistivity					(Å)	ϵ		
Si	1.11	1350	480	2.5×10^{-3}	i	i	n,p	D	5.43	11.8	2.33	1415
Ge	0.67	3900	1900	43	i	i	n,p	D	5.66	16	5.32	936
SiC(α)	2.86	500		10^{-10}	i	i	n,p	W	3.08	10.2	3.21	2830
AlP	2.45	80		10^{-3}	i	i	n,p	Z	5.46		2.40	2000
AlAs	2.16	180		0.1	i	i	n,p	Z	5.66	10.9	3.60	1740
AlSb	1.6	200	300	5	i	i	n,p	Z	6.14	11	4.26	1080
GaP	2.26	300	150	1	i	i	n,p	Z	5.45	11.1	4.13	1467
GaAs	1.43	8500	400	4×10^{-3}	d	d	n,p	Z	5.65	13.2	5.31	1238
GaSb	0.7	5000	1000	0.04	d	d	n,p	Z	6.09	15.7	5.61	712
InP	1.28	4000	100	8×10^{-3}	d	d	n,p	Z	5.87	12.4	4.79	1070
InAs	0.36	22600	200	0.03	d	d	n,p	Z	6.06	14.6	5.67	943
InSb	0.18	10^5	1700	0.06	d	d	n,p	Z	6.48	17.7	5.78	525
ZnS	3.6	110		10^{10}	d	d	n	Z,W	5.409	8.9	4.09	1650†
ZnSe	2.7	600		10^9	d	d	n	Z	5.671	9.2	5.65	1100†
ZnTe	2.25		100	100	d	d	p	Z	6.101	10.4	5.51	1238†
CdS	2.42	250	15	10^5	d	d	n	W,Z	4.137	8.9	4.82	1475
CdSe	1.73	650		10^5	d	d	n	W	4.30	10.2	5.81	1258
CdTe	1.58	1050	100	10^{10}	d	d	n,p	Z	6.482	10.2	6.20	1098
PbS	0.37	575	200	5×10^{-1}	i	i	n,p	H	5.936	161	7.6	1119
PbSe	0.27	1000	1000	10^{-3}	i	i	n,p	H	6.147	280	8.73	1081
PbTe	0.29	1600	700	10^{-1}	i	i	n,p	H	6.452	360	8.16	925

CONCEPT OF HOLE IN SEMICONDUCTORS

The hole, or the deficit produced by removing an electron from the valence bond/covalent bond of the crystal. Although the hole and its negative counterpart, the excess electron, have been prominent in the theory of solids of the work of A.H. Wilson in 1931, the announcement of the transistor in 1948 has given holes and electrons new technological significance. From the theoretical point of view, the hole is in abstraction from much more complex situation and the achieving of this abstraction in a logical way appear to involve rather detailed quantum mechanical treatment. From the experimental point of view, in contrast, the existence of holes and electrons as positive and negative charge carriers of current can be inferred directly by the experimental techniques of transistor electronics.

For understanding the physics of diodes and transistors it is convenient to consider hole as a specific particle. Hole in motion constitute electric current to the same extent that electrons in motion constitutes a electric current. There are however some differences in their behavior in electric and magnetic field which we must keep in mind.

1. Hole can exist only in a semiconductor material such as in Germanium and silicon. This is because, hole depends for its existence on a specific arrangement of electrons (covalent bond). Holes generally do not found in good conductors such as copper and aluminium. Although there is exception in case of beryllium, cadmium, and tungsten where hole conduction has been reported using positive sign of Hall coefficient.

2. The hole is deflected by electric and magnetic field in same manner as that of an electron. Because the hole possesses a charge equal and of opposite in nature to that of an electron, the direction of deflection of the holes in an electric field is opposite to that of an electron. For example the electron is deflected towards the positive plate, the hole moves towards the negative plate. However in magnetic field electrons and holes move in the same direction.

3. When the hole is filled by an electron from the adjacent covalent bond the hole have considered as having moved from one position to the other in the crystal lattice. When a hole is filled by a free or excess electron, the hole no longer exists.

4. The introduction of hole terminology makes the things symmetrical on the two sides of the band gap. The conduction increases the population of conduction band by free electrons. The conduction also increases the populate valence band by holes. At $T = 0\text{ K}$ the valence band is also empty band as far as the holes are concerned.

5. The fundamental theory is that— Current conduction is not possible in empty or filled bands. Why? The statement about the empty band is obvious, since current is not possible without the presence of carriers in the conduction band. The question of conduction in a filled band must be discussed in more details.

The valence band (and the bands below it) is completely filled at $T = 0\text{ K}$ that is every energy level contains two electrons. According to the Pauli's exclusion principle, this is the maximum number they can have. Such a theory has an interesting consequences. The valence electrons are traded between atoms and thereby move about the crystal, but cannot be accelerated and therefore do not contribute to the conduction. Application of an electric field cannot result in acceleration in the filled band, because electron then should then gain energy; but there are no higher energy levels available to which they could rise. The theory of non conduction in empty or filled bands is of fundamental interest. At $T = 0\text{ K}$ conduction is not possible because $\text{BOUND ELECTRON} = \text{free electron} + \text{hole}$, and at $T = 0\text{ K}$ thermal energy is insufficient to break the covalent bond (bound electron) in free electrons and holes.

6. According to the band theory of solids the electrons in the zone boundaries are accelerated in a direction opposite to that of an electron. The electron with negative mass can be considered as a new entity having the same positive mass as that of the electron and the same positive charge having the same numerical value of the electron charge. This new entity is given the name hole. The holes are not real particles like electrons or positrons, but it is only the way to look at the negative mass behaviour of electron near the zone boundaries. We look upon the motion of the effective negative mass electrons as the motion of positively charged holes.

7. If holes are not the real particles then what type of particles they are? A hole plays the role of an antiparticle with respect to an electron. The two may even annihilate. Particles and holes in a Fermi gas and moving particles in Bose gas are sometimes called QUASIPARTICLES OR AS IF THEY ARE PARTICLES but actually they are not.

Quasiparticles are the collective motions of particles in a solid appearing on the atomic scale.

Quasiparticles are but the actual particles of the gas. The number of quasiparticles are not conserved.

7. The existence of positive charge carriers is indicated by the positive value of Hall Coefficient. From the Cyclotron resonance experiments, it has been established that holes and electrons 'rotate' in opposite direction in a magnetic field.

8. A hole in the atoms of a semiconductor means the absence of one of its proper electrons, while the motion of hole is collective relay motion of electron.

9. The cooperative motion of the valence electrons in the crystal lattice is referred to as the motion of holes. It is therefore preferable to consider the motion of a fictitious particle or quasiparticle rather than the more complicated collective motion of all remaining electrons in the valence band.

10. The hole is not necessarily located in the immediate vicinity of the impurity atoms as it always attracts a nearby outer electrons to fill the gap in the structure, and a hole 'moves' elsewhere. Holes are formed in covalent bond that makes a hole, merely removing an electron from a neutral atom does not create a hole in the semiconductor sense of word. This is because by simply removing an electron from the neutral atom will create an ion which contains electrons, protons and neutrons with different masses which makes the ion heavy, and it is difficult to move such ions with electric field.

Therefore one can conclude that a hole is created only when the electron (bound) held in covalent bonded solids is removed by any of the processes by thermal energy, irradiation of electromagnetic radiation or by the bombarding the materials with the some nuclear particles. As a consequence of broken covalent bonds, there exist two distinct and independent groups of charge carriers that can support electric currents in semiconductors. The free electrons, which are produced when a valence electron "shakes loose" from a bond, constitute one class of charge carrier. These free electrons (or conduction electrons), which carry a charge of $-q$, can move about within the semiconductor, under the action of electric field or under concentration gradient, thereby producing total current which is the algebraic sum of drift and diffusion in the same manner that the free electrons in metal produce current.

The other charge carrier is associated with the valence electrons which remain tied up in covalent bonds. Clearly a broken bond is associated with a localized region of positive charge; in the neighbourhood of the broken bond there is an excess amounts to $+q$. This region of positively charge is called a hole because it results from a defect or vacancy in the bond structure.

It is not so obvious that the hole can move about in the semiconductor independently of the conduction electrons. Motion of the localized positive charge does occur because a valence electron in the bond near the broken bond (that is near the hole) can fill the vacancy, thus causing the hole to move in the opposite direction. The valence electron can move in this manner from bond to bond without ever acquiring enough energy to become free of the bond structure.

Therefore, the hole can move throughout the material without involving in any way the electron. Figure illustrates this process.

The independent motion of the conduction electrons and the holes can be visualized in terms of the simple "parking garage analogy" illustrated in figure. The garage has two floors, and contains just enough cars to fill one floor "wall to wall" Figure(a). Clearly, no motion of the cars is possible. If a car (valence electron) is boosted from the first floor (participation in covalent bond) to the second floor (where it is analogous to a conduction electron) shown in fig.(b), two independent kinds of motion are possible. The car on the second floor can obviously move throughout the second floor of the garage; this is analogous to the freedom of motion of the conduction electrons. Furthermore, cars that remains on that floor, it is best describe in terms of the vacancy; this is analogous to the freedom of motion of the hole.

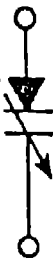
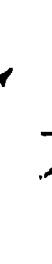
In essence, the concept of hole as a mobile carrier of positive charge is an artifice that allows us to describe, in a simple and elegant way, the relatively complex motion of the assembly of all the bound valence electrons.

The concept of hole is analogous to that of a bubble in a liquid: although it is actually the liquid that moves, it is easier to talk of the motion of the bubble in the opposite direction.

6/10/22

Semiconductor Devices

Table 2: Semiconductor Devices

name of device	symbol	material	physical phenomena	application
Rectifier power diodes		germanium; silicon	unilateral conduction	power conversion and control, wave shaping and instrumentation, receiver detectors and mixers, switching and logic circuits
Small diodes		selenium	avalanche breakdown	voltage reference element in regulator and limiter circuits
Breakdown (Zener) diodes		silicon	voltage-controlled depletion layer thickness	voltage-controlled capacitors in rf resonant circuits; rf frequency multipliers
Varactor diodes		silicon; gallium arsenide		ultrahigh-frequency (UHF) oscillators and amplifiers
Tunnel (Esaki) diodes		germanium; gallium arsenide	guided minority-carrier flow (tunnelling) producing negative-resistance effects	UHF switching and detection
Schottky "hot carrier" diodes		gallium arsenide	majority-carrier conduction through metal-to-semiconductor junctions	frequency multipliers; UHF switching
Step-recovery diodes		gallium arsenide	charge-controlled carrier lifetime	microwave de-controlled switches and modulators
P-I-n diodes		gallium arsenide	variable conductance in the forward-biased region	microwave solid-state generator
Gunn and Impact diodes		germanium and selenium compound	conductive or generative modulation by radiation	light and infrared detector and sensors
Light-emitting diodes		gallium arsenide	radiation emission due to electron-energy-level transition	display system and instrumentation

*No standard symbol.

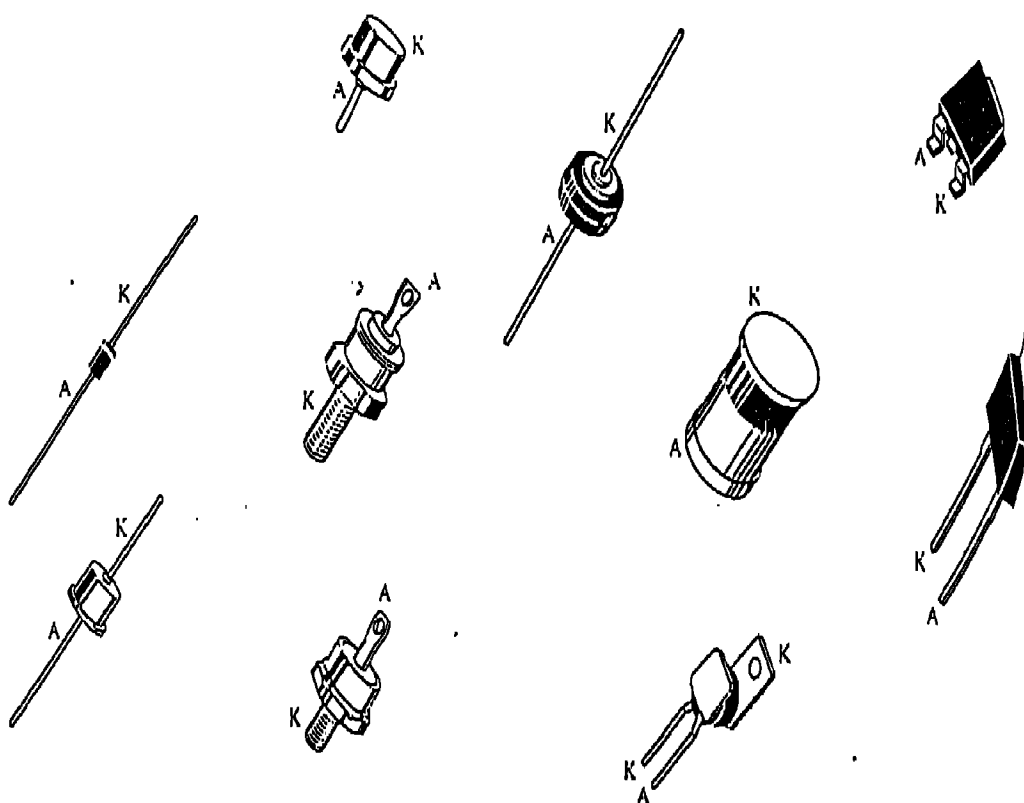


FIGURE 16-25
Typical diode packages and terminal identification.

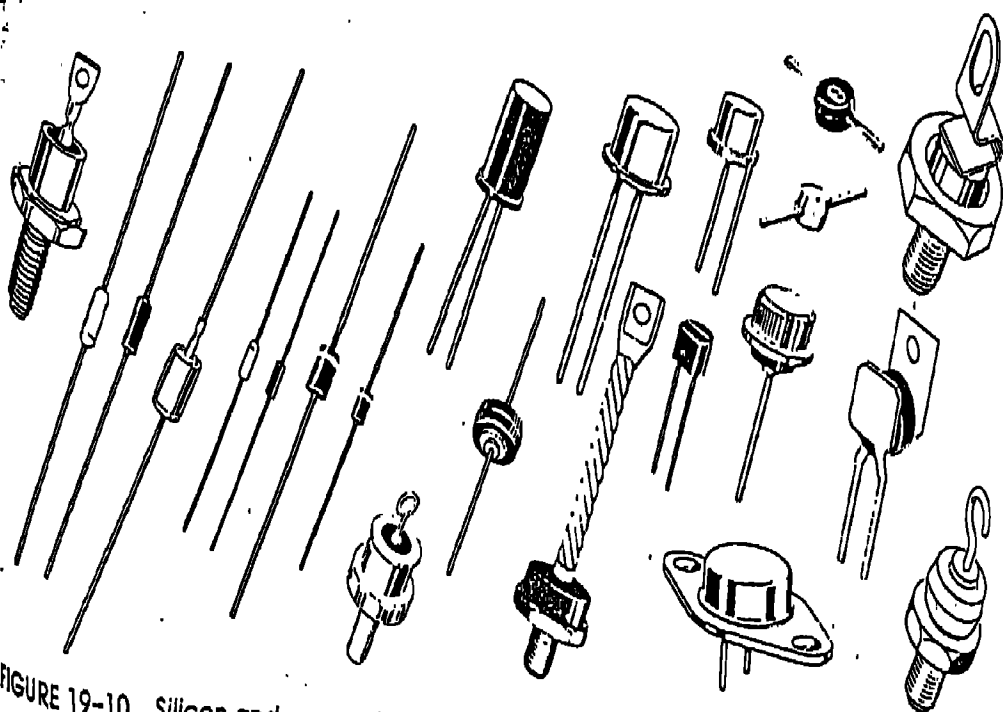


FIGURE 19-10 Silicon and germanium diodes.

Semiconductor diode : -P-type and N type materials taken separately are of very limited use. If we join a piece of P-type material to a piece of N-type material such that the crystal structure remains continuous at the boundary, a PN junction is formed. Such a PN junction makes a very useful device.

A PN junction cannot be made by simply pushing the two pieces together; this would not lead to a single crystal structure. Special fabrication techniques are needed to form a PN junction.

A PN junction itself is an important device. Furthermore, practically all semiconductor devices contain at least one PN junction. For this reason it is essential to understand how a PN junction works and behaves when connected in an electrical circuit.

The most important characteristic of a PN junction is its ability to conduct current in only one direction. In the other direction it offers a very high resistance.

Figure shows a PN junction just immediately after it is formed. It is a single crystal. Its left half is P-region and the right is N-region. The P-region has holes as majority carriers, electrons as minority carriers and immobile charged impurity ions. Whereas in N-region electrons are the majority carriers and holes are in minority and positively charged ions. Electrons and holes are mobile whereas the ions do not move when electric field is applied to the junction. The sample as a whole is electrically neutral and so are the P- and N-regions considered separately. (?)

As soon as the PN junction is formed, the following processes are initiated:-

1. Holes from the P region diffuse in to the N region. They are then recombined with the free electrons in the N region.
2. Free electrons from the N-region diffuse in the p-region. These electrons combine with the holes.
3. The diffusion of electrons and holes takes place as a result of difference in their concentrations on the two sides.
4. One would normally expect the holes in the P-region and free electrons in N-region to flow towards each other and combine. Thus, all the holes and the free electrons would have been eliminated. But in practice this does not occur. The diffusion of holes and the electrons across the junction occurs for a very short time. After a few recombinations of holes and the electrons in the immediate neighbourhood of the junction, a restraining force is set up automatically. This force is called a barrier. Further diffusion of holes from P-region is stopped by the charges on the immobile positive ions of N-region, similarly the diffusion of electrons from N-region is stopped by the negative charges of the immobile ions.
5. Some of the holes in the P-region and some of the electrons in the N-region diffuse towards each other and recombine. Each recombination eliminates a hole and a free electron. In this process, the negative acceptor ions in the P-region and positive

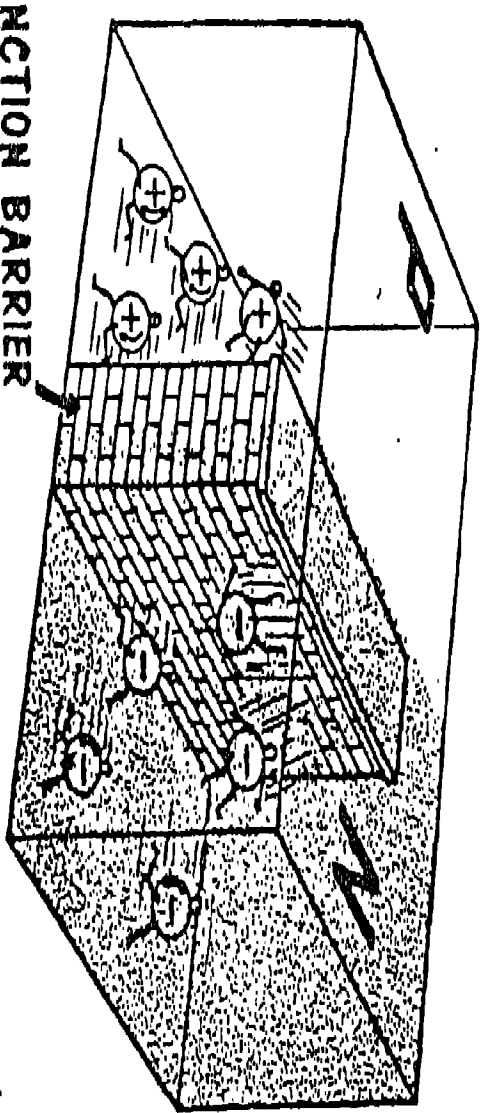
donor ions in the N-region in the immediate neighbourhood of the junction are left uncompensated. This situation has been depicted in the figure. Additional holes trying to diffuse in to the N-region are repelled by the uncompensated positive charges of the donor. The electrons trying to diffuse in to the P-regions are repelled by the uncompensated negative charges on the acceptor ions. As a result, total recombination of holes and electrons cannot occur.

6. The region containing the uncompensated acceptor and donor ions is called the depletion region. That is, there is a region which is depleted of mobile charge carriers. Since this region has immobile (fixed) ions which are electrically charged it is also referred to as space charge region. The electric field between the acceptor and the donor ions is called a barrier or potential barrier. The physical distance from one side of the barrier to the other is referred to as the width of the barrier. The difference of potential from one side of the barrier to the other is referred to as the height of the barrier. With no external batteries connected, the barrier height is of the order of tenths of a volt. For a silicon PN junction the barrier height is 0.7 V, whereas for the germanium PN junction it is approximately 0.3 V.

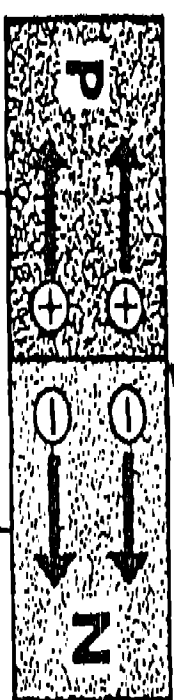
Now the question is that can we be able to measure this potential with the instruments we have in the laboratory? The answer is NO, because the instrument which measures this potential will draw some current and the equilibrium of the carriers will be disturbed.

7. The barrier discourages the diffusion of majority carriers across the junction. But what happens to the minority carriers? There are few electrons in the P-region and few holes in the N-region. The barrier will help these minority carriers to drift across the junction. The minority carriers are constantly generated due to thermal energy. Does it mean there would be a current due to the movement of these minority carriers? Certainly NOT. Electric current cannot flow since no circuit has been connected to the PN junction. The drift of minority carriers across the junction is counterbalanced by the diffusion of the same number of majority carriers across the junction. These few majority carriers have sufficiently high kinetic energy to overcome the barrier and cross the junction. In fact the barrier height adjusts itself so that the flow of minority carriers is exactly balanced by the flow of majority carriers across the junction. Thus we conclude that the barrier voltage is developed across the PN junction even if no external battery is connected.

HOLES and ELECTRONS do not have enough energy to "climb" the *Junction Barrier*, and move away from it

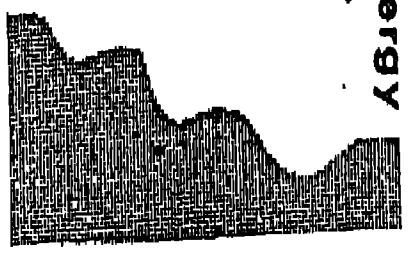


THE JUNCTION BARRIER

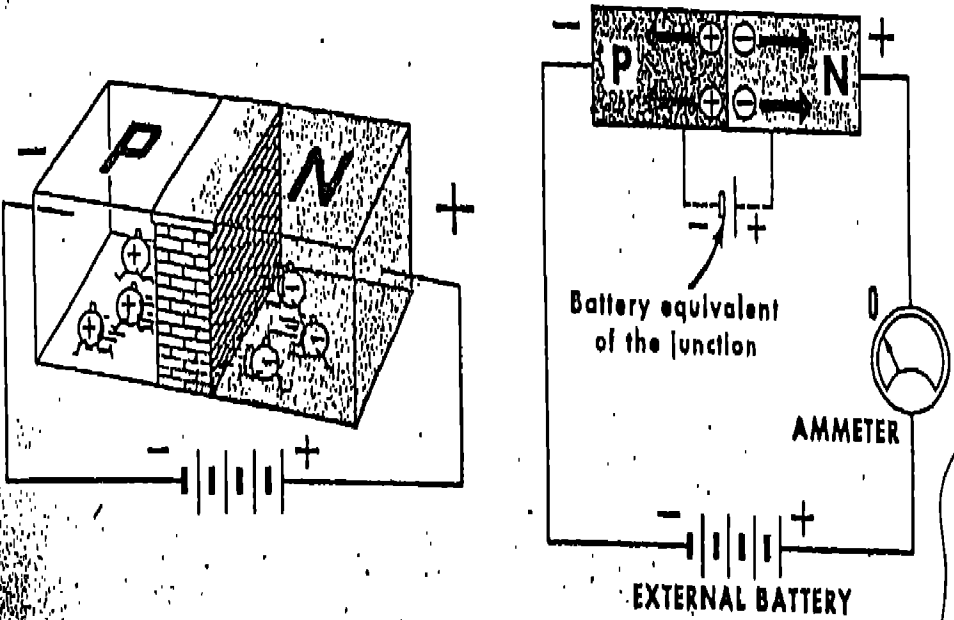


Holes and electrons are repelled from barrier

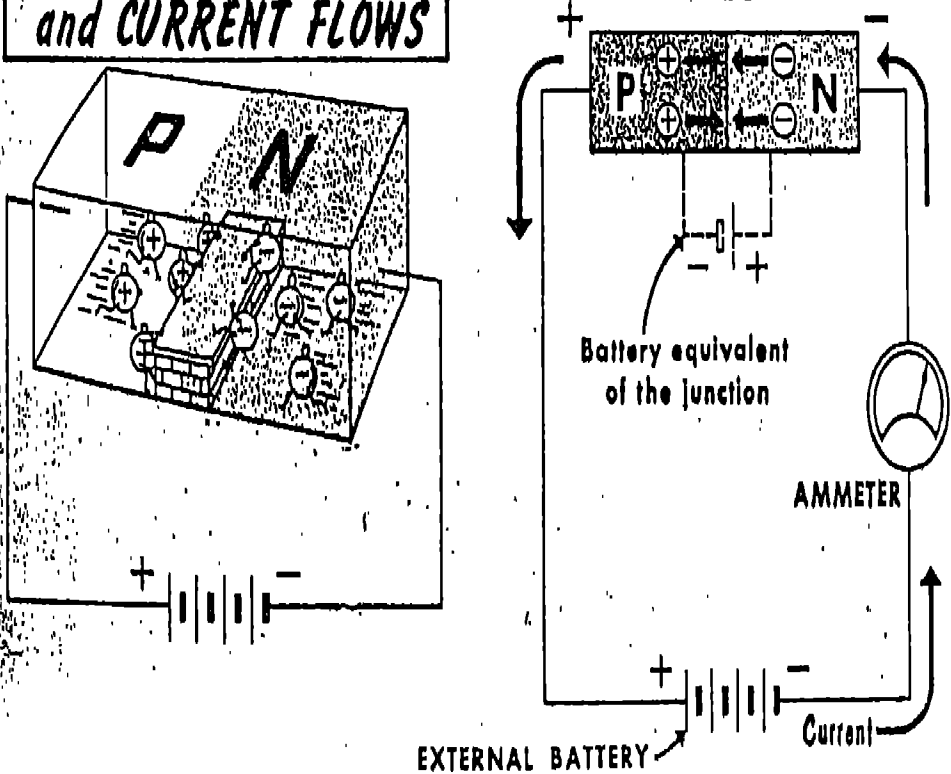
The effect is equivalent to having a small battery connected like this

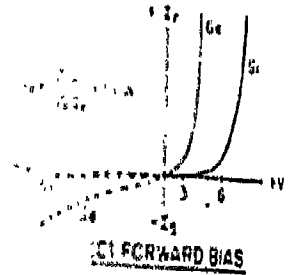
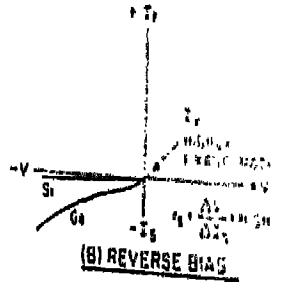
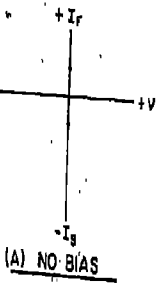
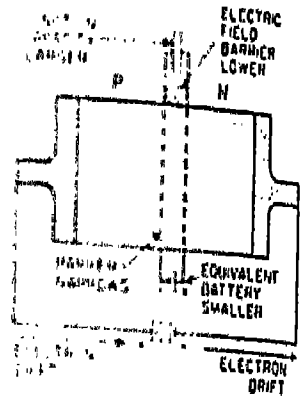
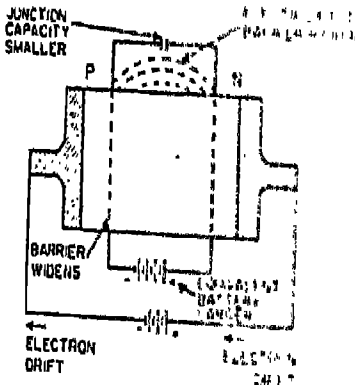
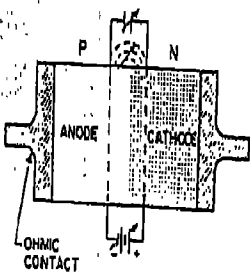
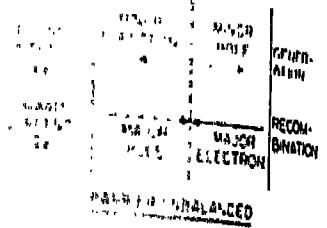
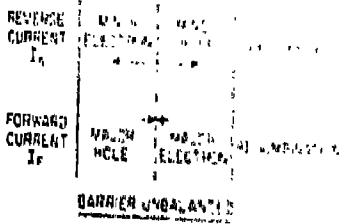
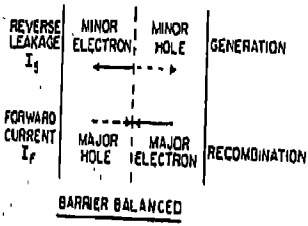


REVERSE BIAS RAISES the JUNCTION BARRIER
and NO current flows



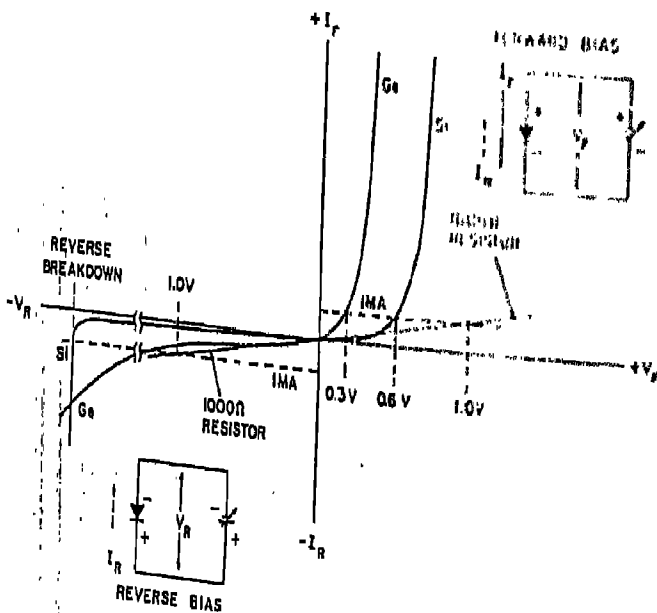
FORWARD BIAS LOWERS the JUNCTION BARRIER
and CURRENT FLOWS





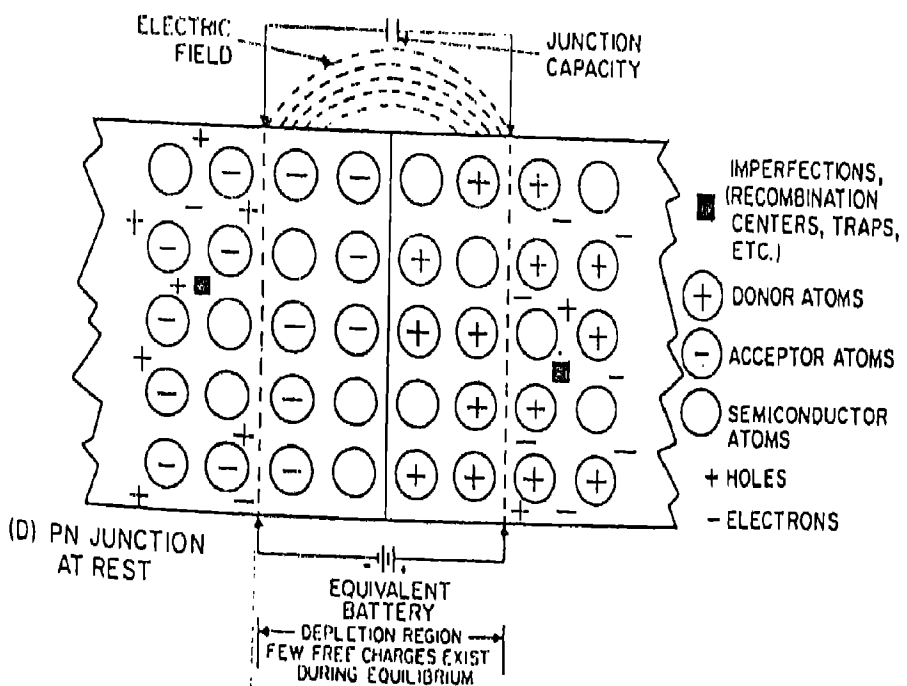
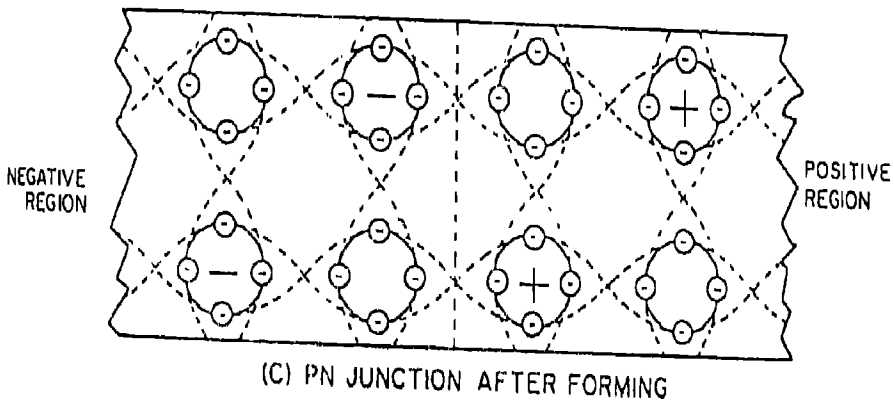
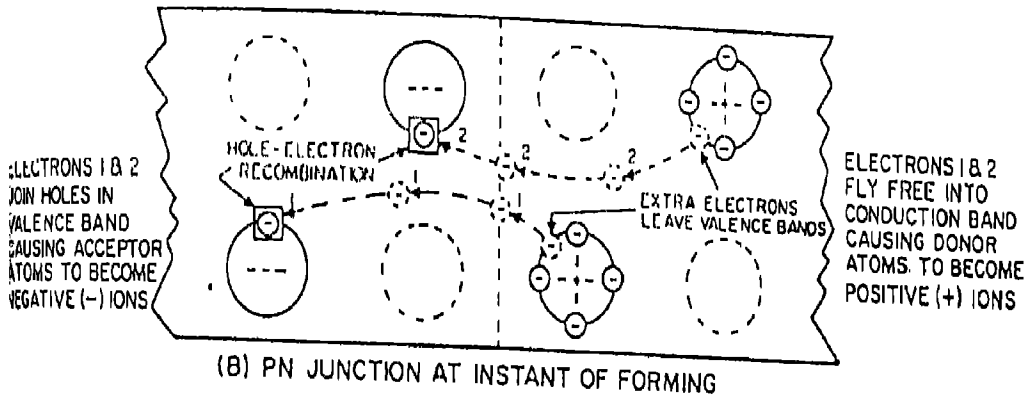
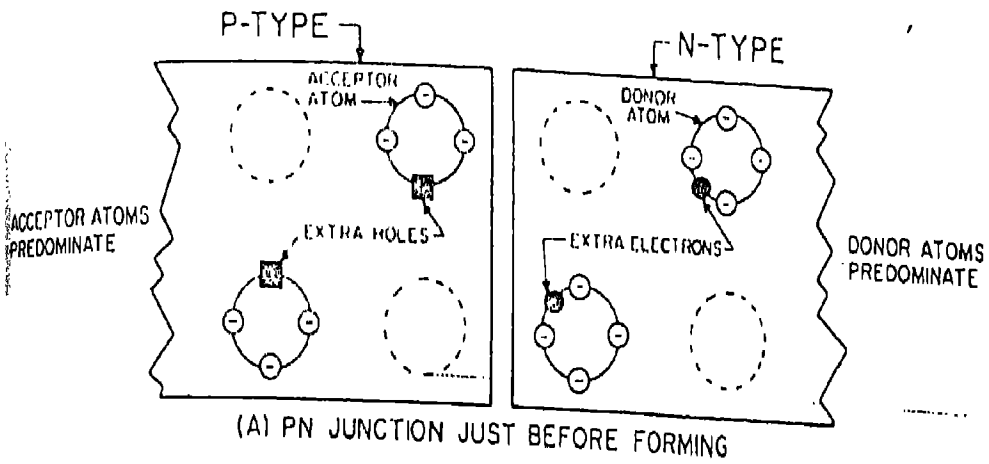
PN JUNCTION BIAS

Figure 10-23

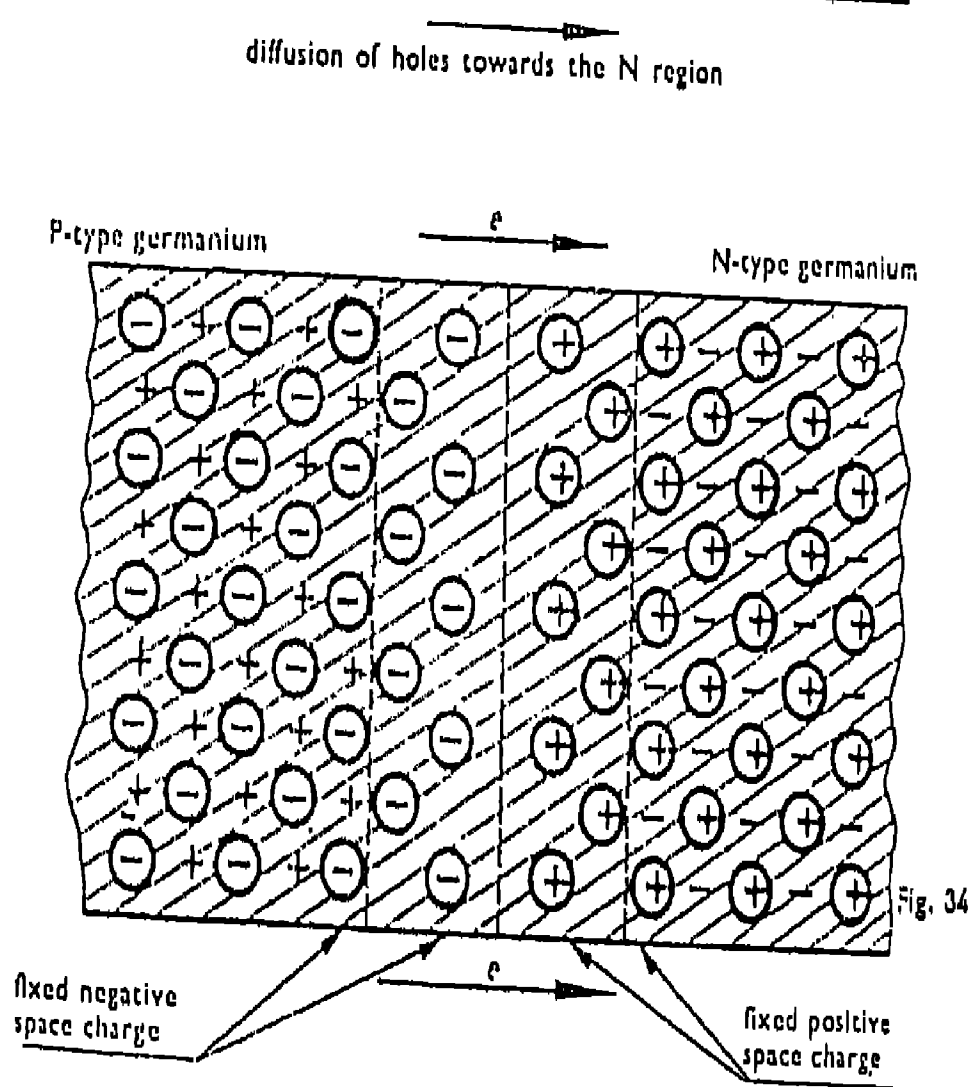
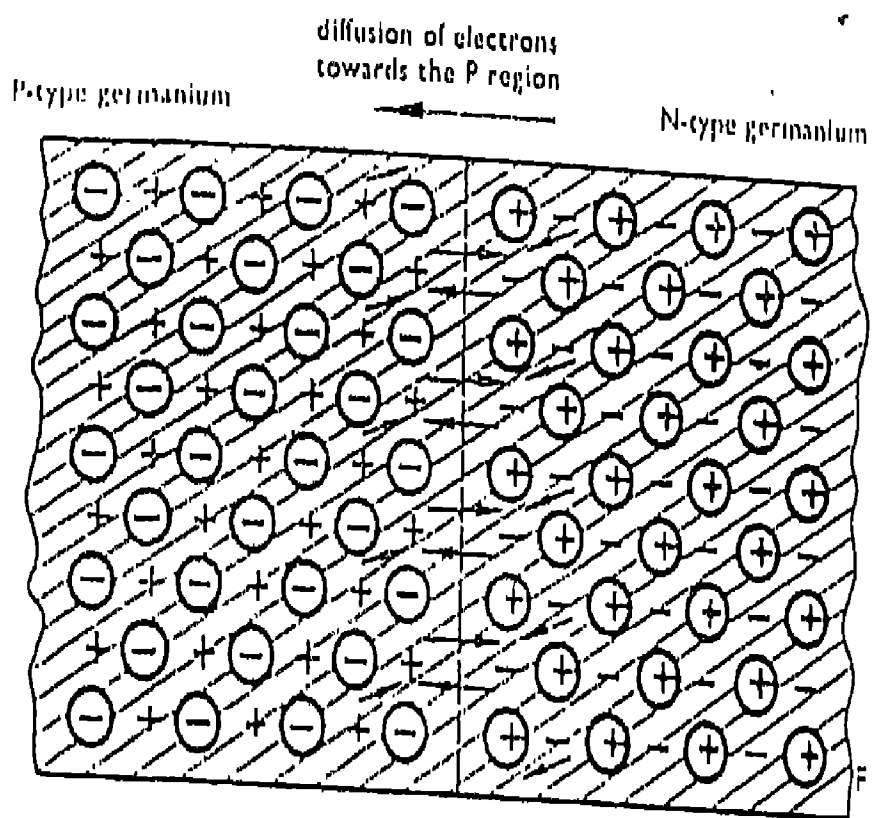


DC CHARACTERISTICS OF RESISTOR, GERMANIUM DIODE, AND SILICON DIODE UNDER INFLUENCE OF FORWARD AND REVERSE BIAS VOLTAGE

Figure 10-24



PN JUNCTION FORMING



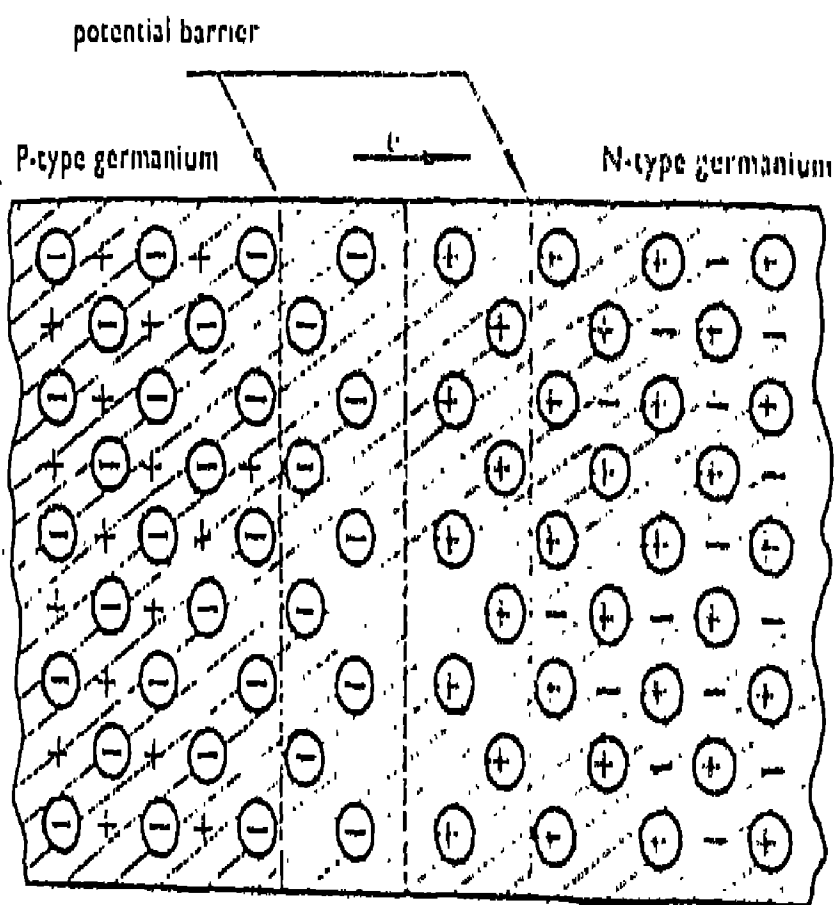
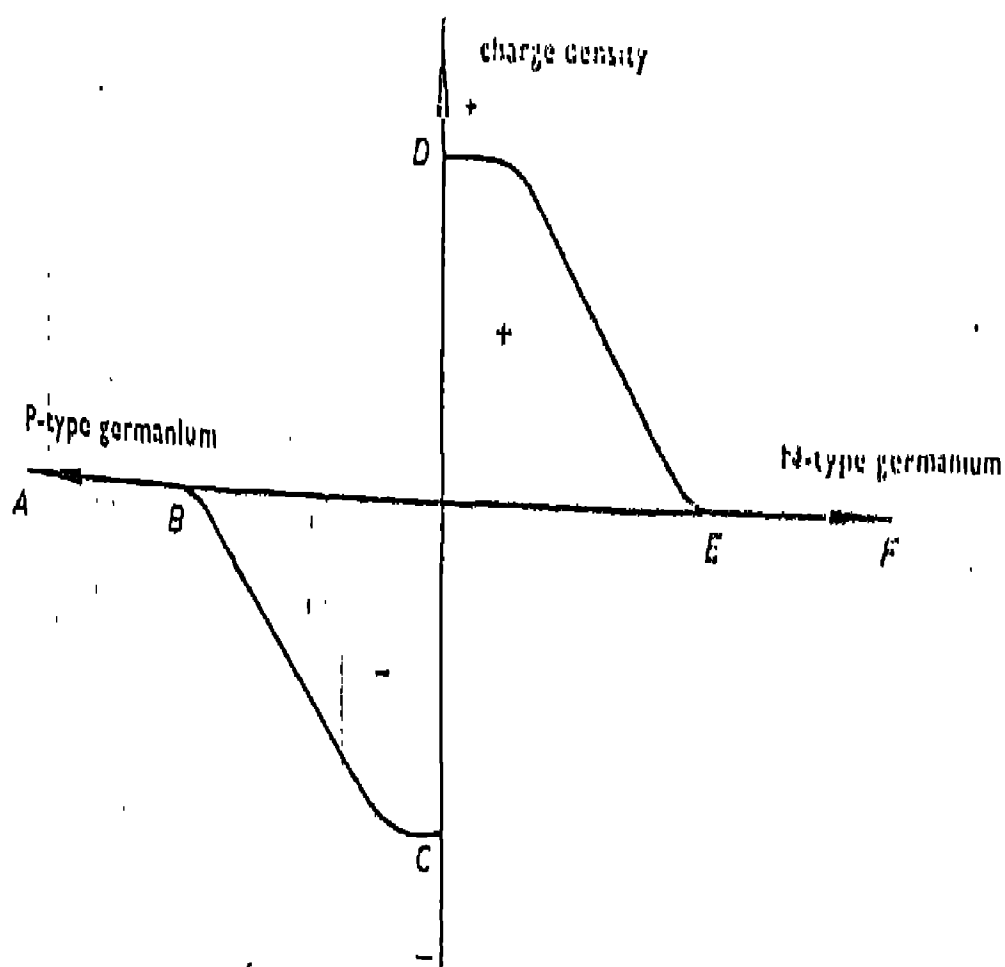
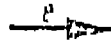


Fig. 30a



P-N JUNCTION - FORWARD BIAS

P-type germanium



N-type germanium

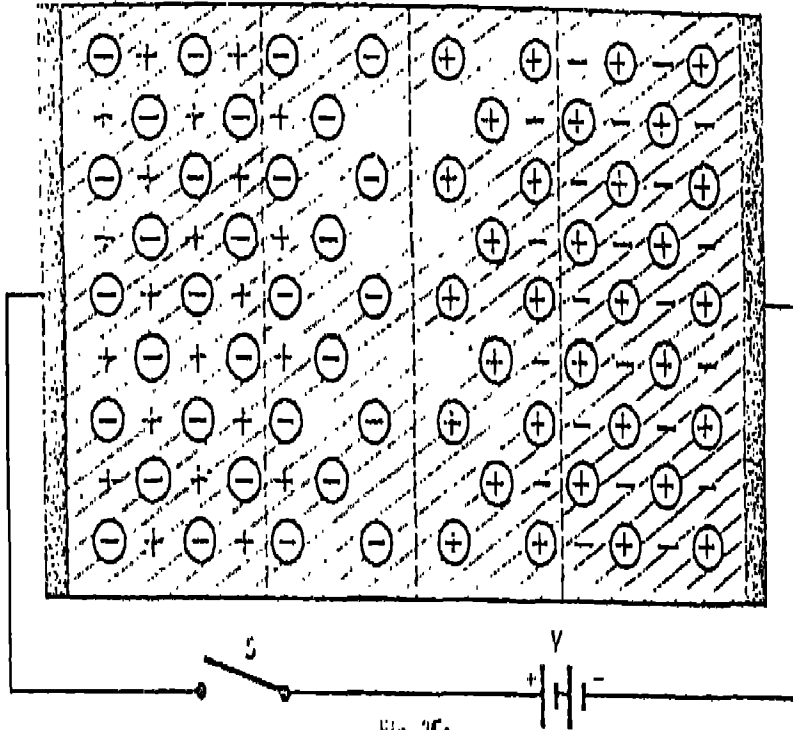
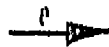


Fig. 35a

P-type germanium



N-type germanium

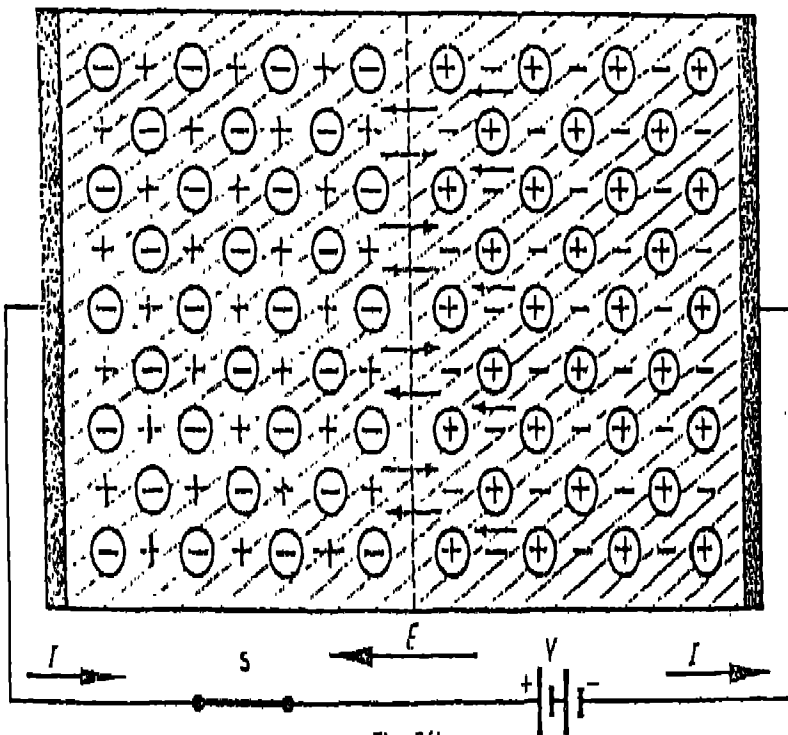
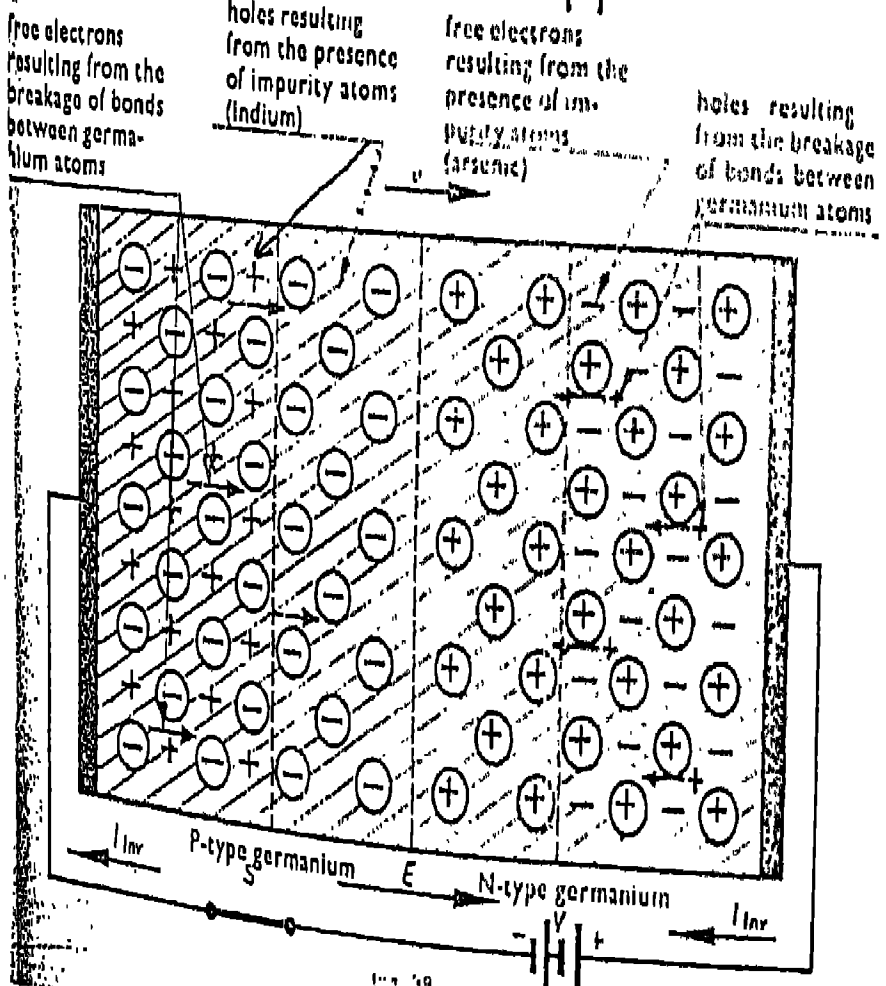
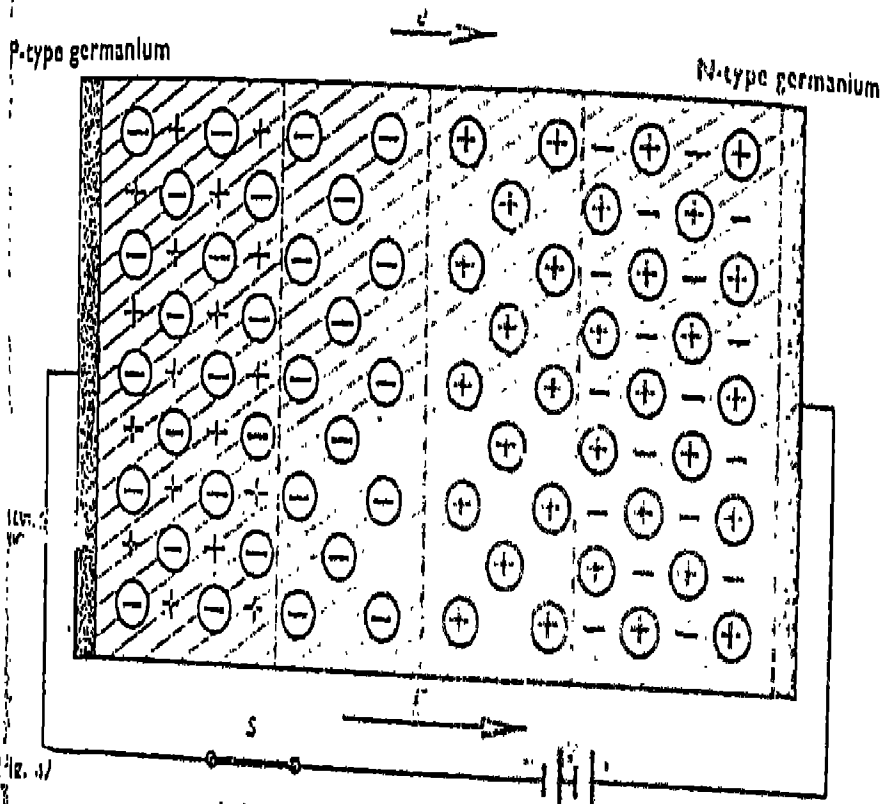
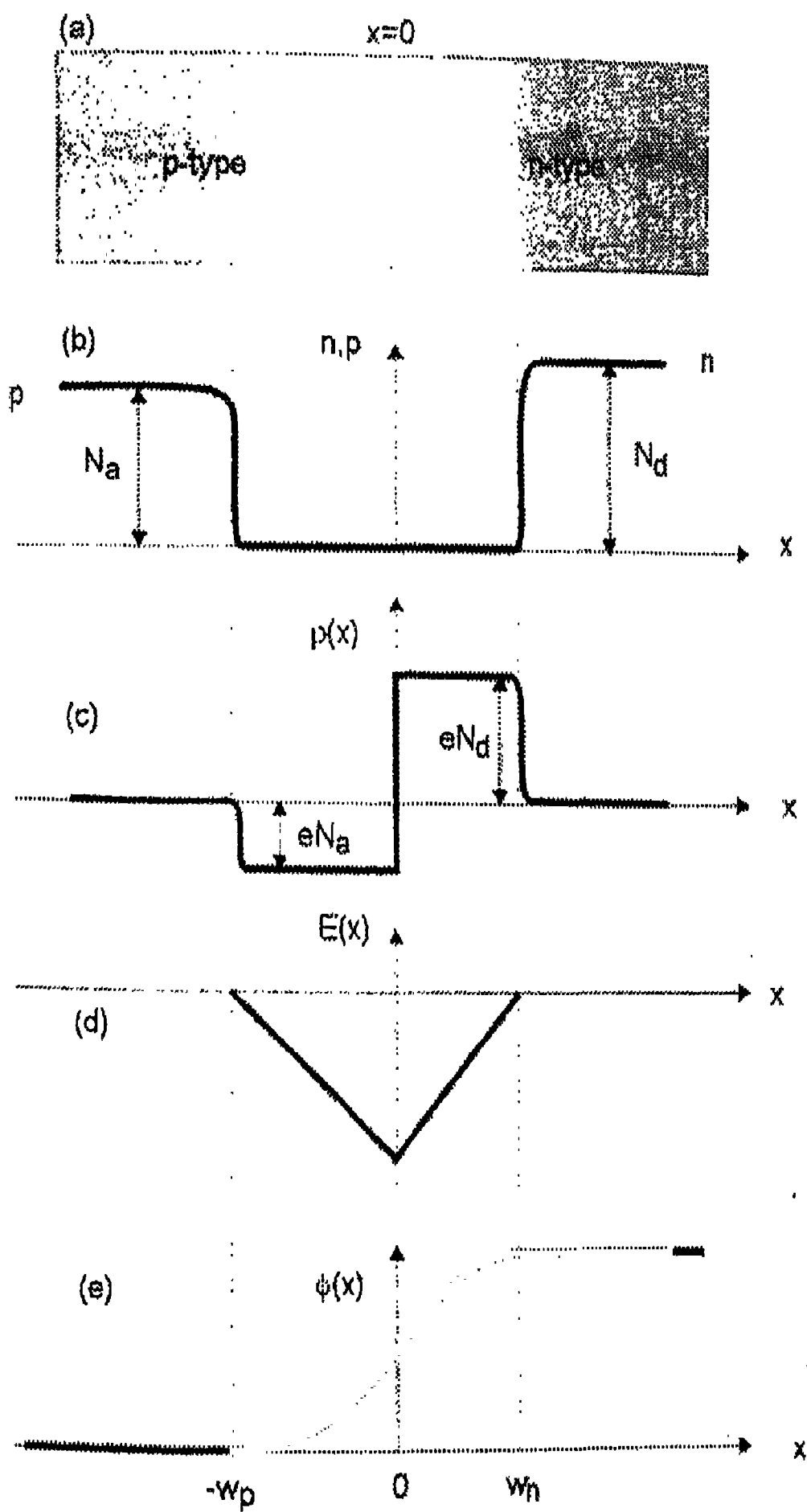


Fig. 36b

PN JUNCTION - REVERSE BIAS





P-N-junction:- Formation of a barrier (potential)

To the left of the reasonably plane, let us say, there is a large value of electron density and scarcely any hole concentration, region I. To the right region II, there are many holes and few electrons. The densities of both electrons and holes are discontinuous at the boundary plane, and diffusion of both carrier types ensues. The migration of holes to left half and electrons to the right continues, setting up a non-equilibrium condition of charge, for the holes carry positive charge to the left while electrons moving to the right take negative charge along. The sample becomes charged up more and more-positive on the left. This immediately creates an electric field in the vicinity of the junction which causes drift currents to flow. In what direction? With the left end positive there is an electric field directed from left to right. Electrons move opposite to the field and drift from right to left, while holes move left to right. But these motions are just opposite to the diffusive flows. Furthermore, the greater the electric field the larger the drift currents will be. Equilibrium is reached when the diffusive flow of electrons is precisely matched by the drift flow of electrons. A similar equilibrium is responsible for zero net hole current across the junction.

This equilibrium demands that there be a higher potential on one side of the boundary than on the other. Can this potential be measured?

voltmeter? The answer is no, because the meter would extract current from the system, and this energy withdrawal would violate our assumption of equilibrium. What does happen is that the energy of a free electron in the conduction band must be different on the two sides of junction. How this can occur is best discussed using the band theory picture for the two regions.

Before reassembling the two halves of the crystal we made sure to dope them differently. This left its mark on the band theory picture of the regions, for the n-type material must have its Fermi level above the center of the forbidden band. Likewise below the middle of the forbidden region (this is really an alternative definition of p-type semiconductor). When the two halves were rejoined, let us say with the valence and conduction bands in alignment, the fermi levels were not matched. The process of diffusive flow, eventually balanced by drift flow, results in the conduction band of the p-type region moving up in energy w.r.t. the n-type. The electric field produced across the junction means that electrons must gain energy to cross from the positive to negative side, and this is shown graphically in the location of the conduction band of the negative material at a higher energy. The final result is that the alignment of the band pictures of the two materials is at the fermi-level, not at the conduction or valence bands. The process is shown in Fig.,2.

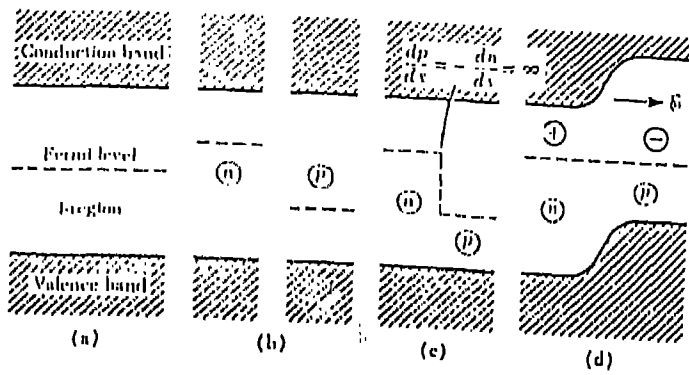


Figure 1.1. Formation of a p-n junction.

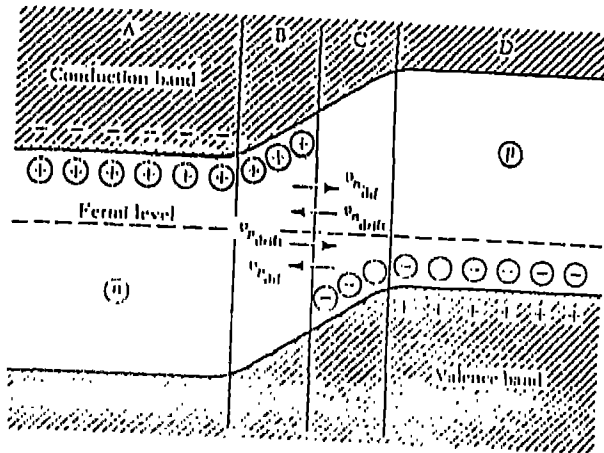


Figure 1.2. Detailed picture of band theory of p-n junction in equilibrium; $+$ $-$ are free holes and electrons, $\oplus$ $\ominus$ are bound impurity ions.

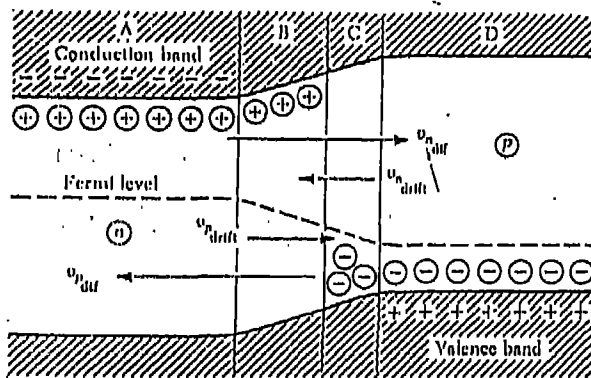


Figure 1.3. The p-n junction with forward bias.

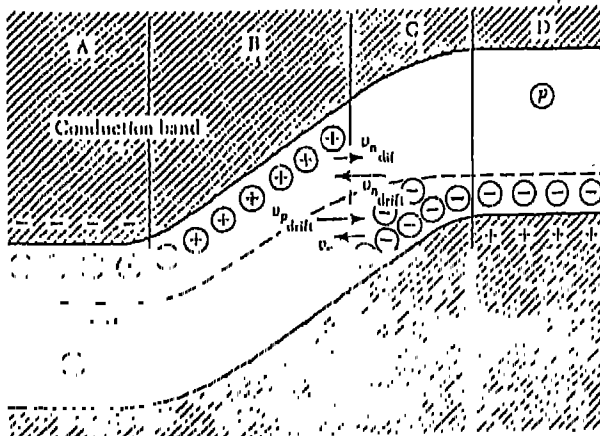


Figure 1.4. The p-n junction with reverse bias. Compare with Figure 1.3.

1. Region A, a normal n-type semiconductor, zero net charge density.
2. Region B, the n side of the junction, net positive charge density, diffusion and drift currents of both holes and electrons passing through, but zero net current.
3. Region C, the p-side of the junction, net negative charge density, compensating hole and electron drift and diffusion currents.
4. Region D, a normal p-type material, charge neutral, no currents.

TRANSISTOR

INTRODUCTION :-

The transistor and the vacuum tube both function as electronic amplifying devices. The amplifying effect in a vacuum tube is based on the control of an electron flow in a vacuum, whereas in a transistor the flow of the charged carriers (electrons and holes) is controlled in a solid state semiconductor body.

Because the amplification function of transistors is similar to that of vacuum tubes and because most students are more familiar with vacuum tubes, some persons are of the opinion that the best method to learn about transistors is to start with the vacuum tube and apply, by analogy, this knowledge to the transistor. The authors believe, however, that this is not a satisfactory procedure, though there is a similarity in circuit behavior between the transistor and the vacuum tube, a marked difference exists in the very mechanism of operation. As can be seen in the following para. a formal analogy can even lead to wrong conclusions as to the behavior of the transistor. The formal analogy drawn only when it will facilitate understanding.

The vacuum tube can be represented as an equivalent resistor whose magnitude is changing with the variations of the control grid bias; the result is the changing current and voltage across the load resistor in the output. Similarly, a transistor can

be conceived as a variable resistor whose magnitude changes with variations of the base current. In fact, the name transistor, implying this concept, is a combination of the words transfer and resistor.

An analogy can be drawn between the functions of the electrodes of a transistor and the function of a triode tube. The emitter can be compared to the cathode, the base to the grid, and the collector to the anode. A further analogy can be drawn with the basic configurations, the CE configuration corresponds to the grounded cathode circuit, the common base CB configuration to the grounded grid circuit, and CC configuration to the cathode follower. Moreover, the electrical characteristics of the transistor and the vacuum tube are very similar. A precaution must be taken, however, with drawing further analogies, lest we come to wrong conclusions. It is always better to conceive the transistor as a separate device with its own physical phenomena.

It is for example, wrong to simply compare the gains of a transistor and of a vacuum tube amplifying stage. Often, our concept about electronic amplifiers come from the vacuum tubes. A general concept is that there is always a power gain with an amplifier. This principle is true for the transistor because its low input resistance must always consume a certain amount of power/energy in the input circuit. A vacuum tube, however, very often has an infinitely large input resistance with no power consumption at the input. Therefore, a vacuum tube as a voltage

amplifier can be conceived only as a special case of the more generalized power amplifier (grid is negatively biased and does not draw any current). Therefore, a vacuum tube as a voltage amplifier can be conceived only as a special case of the more generalized power amplifier.

Another example of the wrong conclusions that can be made with a formal analogy concerns the mutual conductance. Transistors have a G_m of the order of magnitude of 100 millimhos, a very high in comparison with the mutual conductance of a normal vacuum tube. The point is that, because of the small input resistance of the transistor, the input voltage (defined, by the mutual conductance, as a ratio of the anode current to the control grid voltage) is dependent upon other factors in the input circuit, that is, the internal resistance of the signal source. Therefore, in the case of transistor, the input current has a greater meaning than does the input voltage. That is transistor a current operated. From these two examples we can see the basic difference in the application of a transistor or a vacuum tube. For this reason, we must take in to consideration four parameters for the transistor, whereas only three are necessary for a vacuum tube. The output characteristics and the input characteristics are needed to compare the four transistor parameters.

Transistor

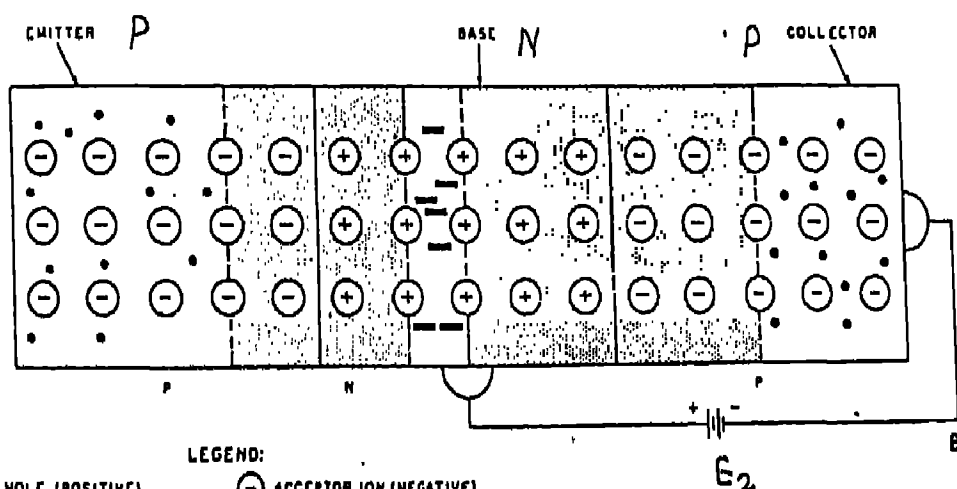
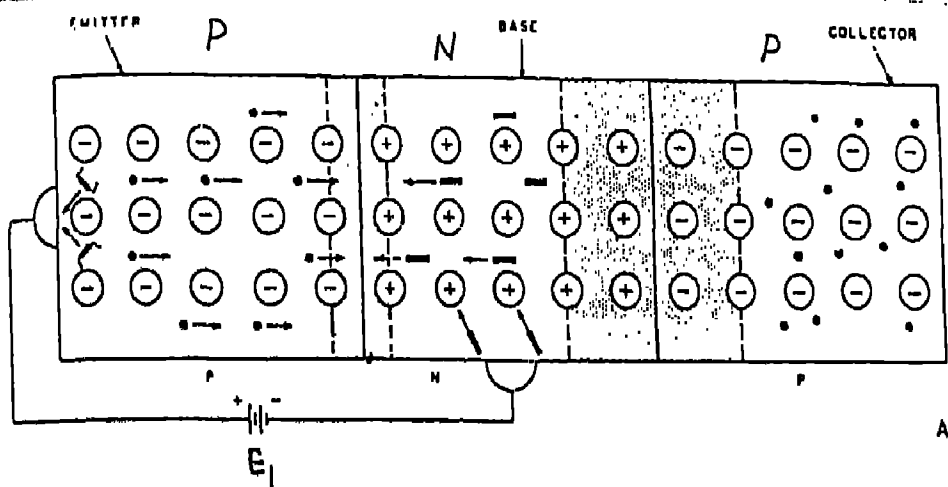
1.

If no collector current flows, either because no emitter current flows or because there is no collector bias, the transistor is said to be cut off.

2. If collector current flows, the transistor is said to be active^{VC}.
3. If the collector current varies rapidly with collector voltage, the transistor is saturated.
4. If the collector current does not vary rapidly with collector voltage but does depend on emitter current, the transistor is operating in its linear operating region.

The operation of a transistor :-

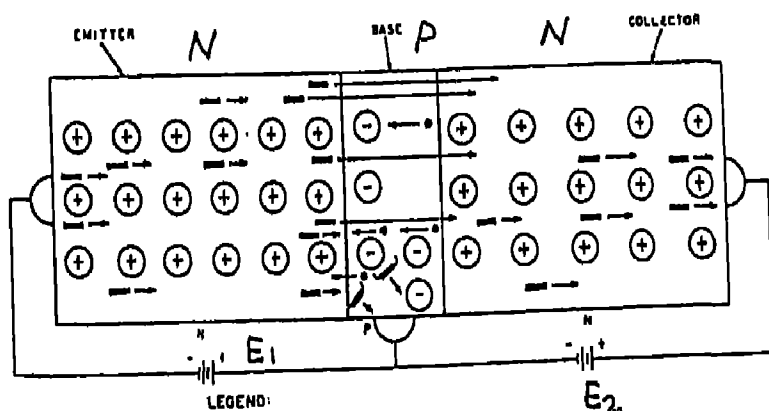
1. The collector-base junction is biased backward. The collector-base depletion region may reach the emitter base junction. If there were only the collector base junction, there would be no current flowing in the collector circuit.
2. If the emitter base junction is biased backward, no current flows in this junction either, and as a result, no current flows anywhere in the transistor circuit. This is a relatively uninteresting situation.
3. The emitter-base junction is biased forward. As a result, holes are injected from the emitter into the base region-this is the source of the name emitter.
4. The holes injected into the base region diffuse away from the base emitter junction, but because of the geometry(it is hundreds of times farther to the base connection than it is to the collector) and because of the



LEGEND:

- HOLE (POSITIVE)
- ELECTRON (NEGATIVE)
- ⊕ DONOR ION (POSITIVE)
- ⊖ ACCEPTOR ION (NEGATIVE)
- ELECTRON FROM ELECTRON-PAIR BOND

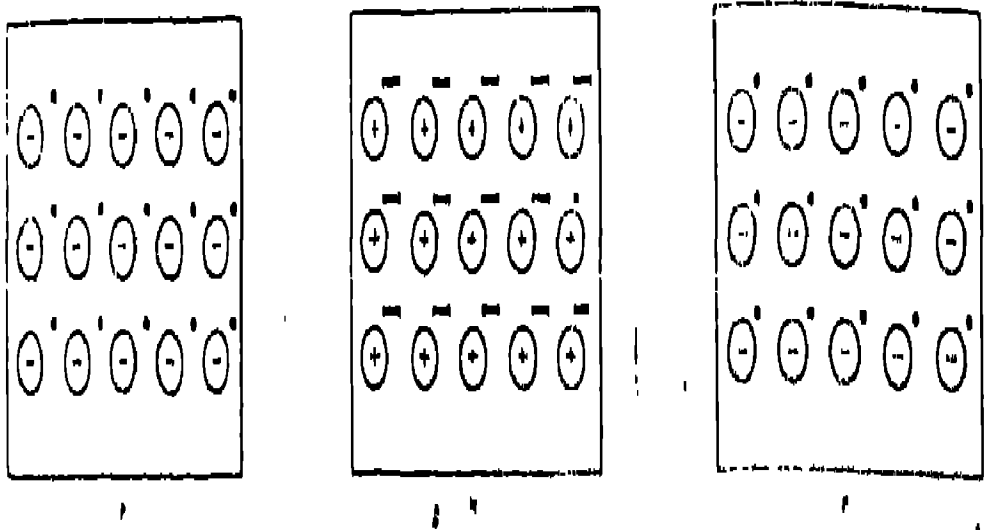
Figure Forward bias between emitter and base (A); reverse bias between base and collector (B).



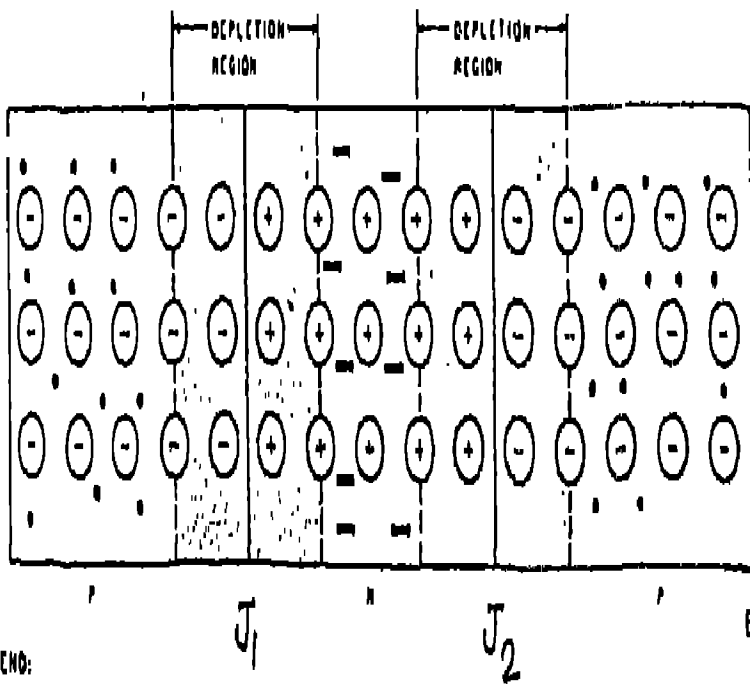
LEGEND:

- HOLE (POSITIVE)
- ELECTRON (NEGATIVE)
- ⊕ DONOR ION (POSITIVE)
- ⊖ ACCEPTOR ION (NEGATIVE)
- ELECTRON FROM ELECTRON-PAIR BOND

Figure Simultaneous application of forward bias between emitter and base and reverse bias between base and collector of an NPN transistor.



A



B

- LEGEND:
- HOLE (POSITIVE)
 - ELECTRON (NEGATIVE)
 - ⊕ DONOR ION (POSITIVE)
 - ⊖ ACCEPTOR ION (NEGATIVE)

Figure Two sections of P-type germanium and one section of N-type germanium, separated (A) and combined (B).

amplifier —
b

AMPLIFIER :- Amplifier is a device for increasing the amplitude or the strength of a weak signal fed to its input terminals. Electronic amplifiers, which are the best known and most important type, are used in huge variety of devices such as radio, television, tape recorder and Hi-Fi (high fidelity) sound systems, multimedia computers, Radar, Servomechanism and electronic equipments.

Other devices which amplify in a different way include binoculars, telescopes and microscopes are basically amplifiers of the object we see, mechanical amplifiers such as pantograph which enlarges drawings, hydraulic amplifiers such as power brakes of car, acoustic amplifier such as air horn and an old fashioned gramophones, fluid amplifiers, used in fluidics and magnetic amplifiers used as theatre light dimmers and in computers.

All electronic amplifiers work in much the same way, though they differ widely in design and in the degree of amplification (gain) they produce. Gain can be measured as a proportional increase in voltage, in current or in wattage (power).

The heart of an amplifier, and the device that actually does the amplification, is either a thermionic tube (valve) or a transistor or an integrated circuit. Nearly all electronic amplifiers have several of these plus a set of resistors, capacitors and inductors to control the current through the basic amplifying components. Vacuum tubes and transistors use different principles to perform the same function. Basically, they act as variable switches where the flow of small current through one part of the device controls the flow of a larger current through another part.

One of the most important characteristics of an electronic signal is its amplitude, frequency and phase. A signal may have a desirable waveform and frequency, and yet be unusable if its amplitude is too small. This is because the circuit or the device that operate in response to signals require definite level (amplitude) for proper operation. A simple example of this is loud speaker. If the signal level is small, the output from the speaker will not be able to hear by our ears.

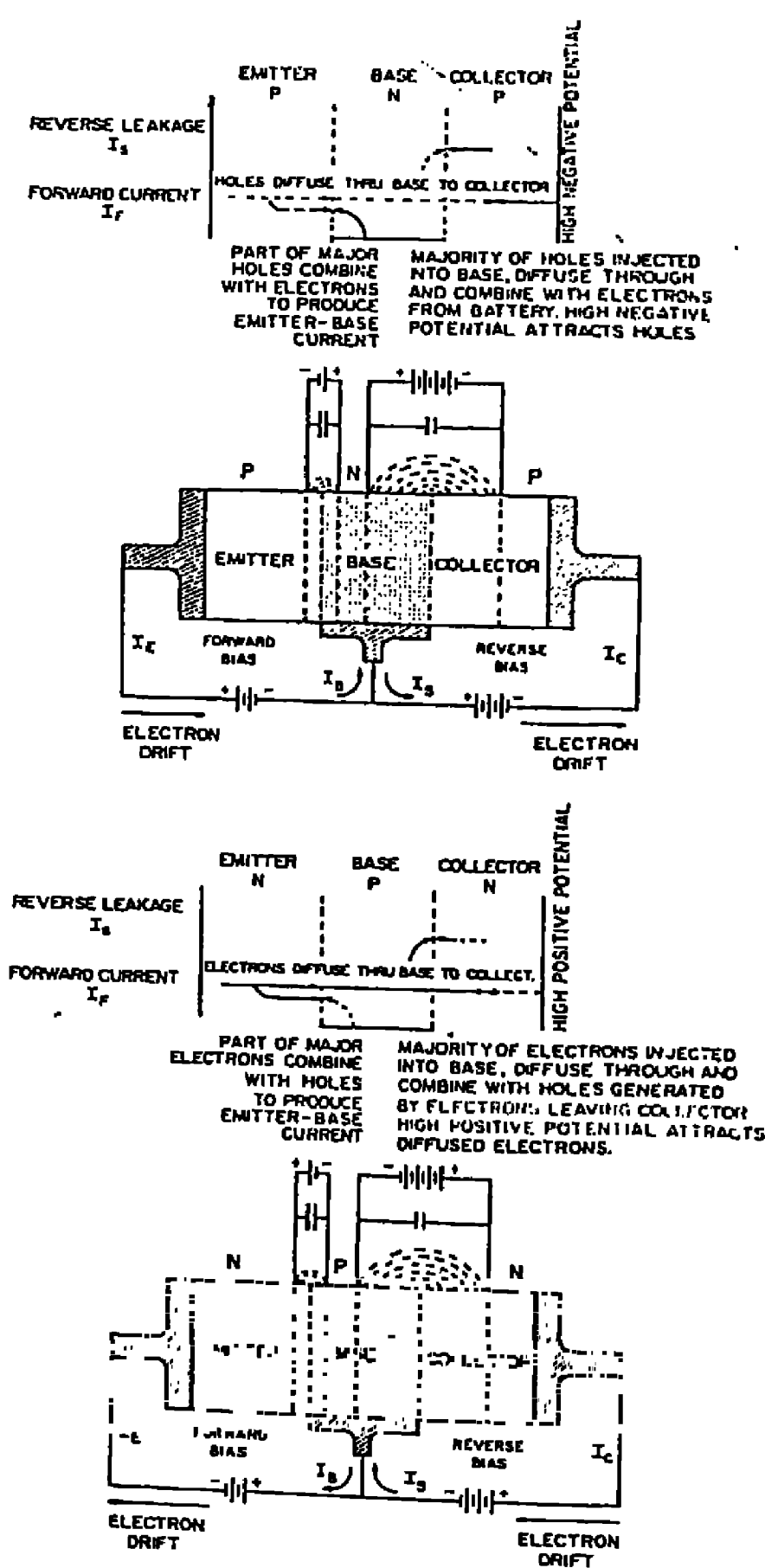
The function of an amplifier is to increase the amplitude of a given signal without affecting the other characteristics such as frequency. Basically an amplifier is a circuit that receives an input signal and delivers a signal the same as the input but with the increase in amplitude. Every electronic amplifier has been characterised by three important properties or characteristics that makes it suitable for some applications and unsuitable for the others. The most important of these are GAIN, BANDWIDTH, & DISTORTIONS. GENERALLY WHEN ONE TRIES TO INCREASE THE GAIN OF ANY AMPLIFIER, ONE GETS DISTORTIONS. The test of an amplifier is that for increased gain one must get minimum distortions.

Gain is the term used to describe how much amplification the amplifier can provide. It is the ratio of output to input voltage, current and power. An amplifier with gain of 20 will deliver an output which will be 20 times the input signal.

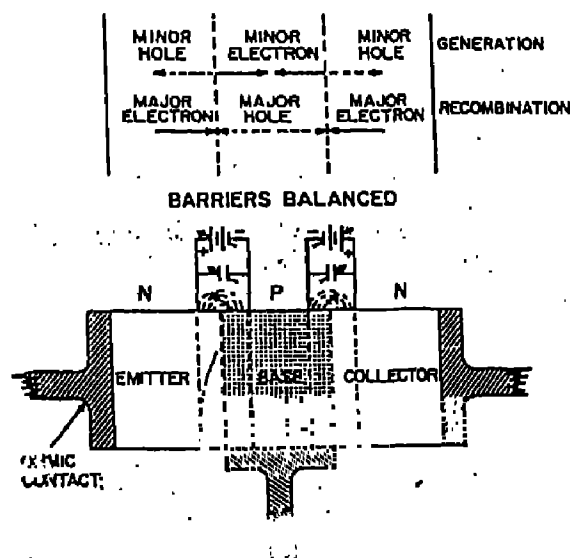
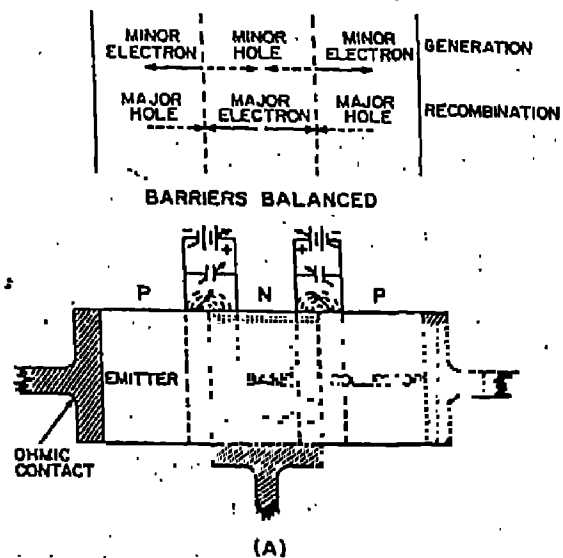
Bandwidth :- Actually the gain of an amplifier is frequency dependent. This means that gain is not constant for all the frequencies under consideration. The way in which the gain of an amplifier changes with frequency of the input signal is described by its frequency response. Normally the frequency response has been expressed by the graph between its gain on Y-axis and log of frequency on the X-axis. The shape of the curve is the characteristic of the amplifier in question. For example for Radio frequency amplifiers the curve is sharp with narrow bandwidth whereas for audio amplifier it is broad and flat.

The bandwidth of an amplifier is the range of frequencies over which the amplifier gain is almost constant and can be achieved by drawing a line horizontally parallel to frequency axis. The range of frequencies between the two points on the frequency response curve at which the gain is 0.707 times its maximum gain, for practical purposes this is usually considered to be the range of frequencies between the two points on the frequency response curve at which the gain is 0.707 times its maximum gain.

DISTORTIONS :- THE OUTPUT OF ANY AMPLIFIER IS EXPECTED TO BE EXACTLY IDENTICAL TO THE INPUT EXCEPT FOR THE INCREASE IN THE AMPLITUDE.

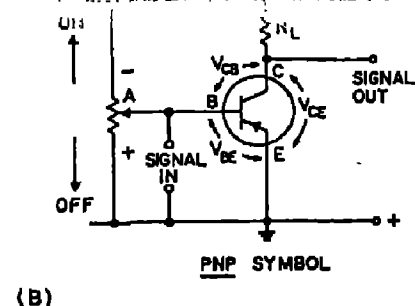
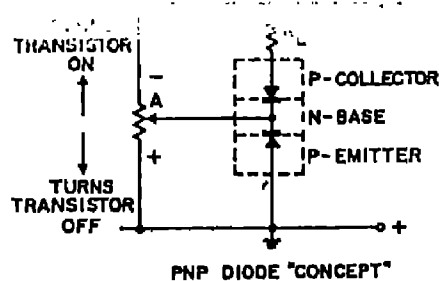
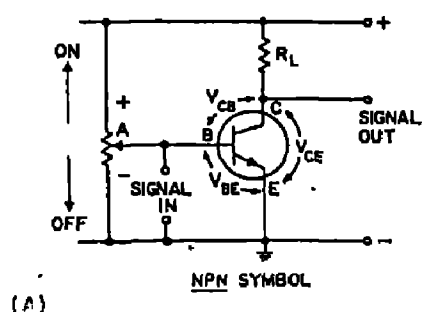
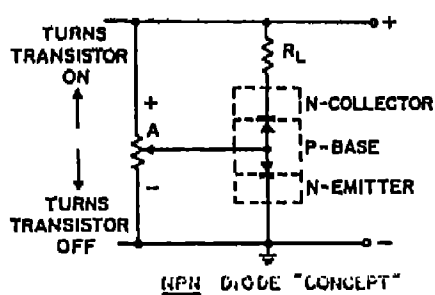


BIASED JUNCTION TRANSISTOR
(COMMON BASE CONNECTION)
Figure



JUNCTION TRANSISTOR

Figure 1.



BASE-EMITTER BIAS ADJUSTMENT TURNS TRANSISTOR "ON" OR "OFF"

reverse bias on the base collection, most of the holes injected into the base are swept in to the collector by the base collector dipole field; only a few are lost to the base. Thus the collector current is slightly less than, but almost equal to the emitter current. Remember that holes in the n-type base are minority carriers and the fields in the depletion region push them towards collector. Clearly, the name collector comes from the collection of the minority carriers in the base.

Amplifier:- An electronic amplifier is a device or system that increases the amplitude level hence intensity of a given signal ^{that is} applied to its input terminal, without appreciable changes in the other characteristics like frequency etc.,

Characteristics of an Amplifier:- Amplifier must have the three characteristics (i) gain (ii) band width (iii) distortion

Gain - Gain of an amplifier is the ratio of output voltage to the input voltage known as voltage gain (A_v)

Ratio of output current to input current is called current gain, for common emitter current gain is represented by β , and the current gain in common base as α , both are interrelated by expression $\beta = \frac{\alpha}{1-\alpha}$

Gain of an amplifier is frequency dependent.

Bandwidth:- Bandwidth is the width of frequency band amplified uniformly by a circuit

If you plot gain versus frequency you will get a curve known as frequency response

The bandwidth is the width where the horizontal line at 0.707 of Maximum gain

Distortions - means ^{cuts the frequency response curve} ~~unwanted frequency component after amplification~~

Oscillator :-

Without Oscillators, radio and television would be totally impossible. This is because an Oscillator forms the nucleus of every typical radio and television transmitter and an essential part of every superheterodyne radio receiver. In television reception, oscillatory circuits are equally indispensable. So, the oscillator is, in many respects the most vitally important of all electronic circuits. Despite their obvious importance, however, oscillator circuits in their basic forms are usually quite simple.

One might truly claim that an oscillator is the most essential, important and valuable of all electronic communication devices in present use, right from radio to cellular phones, ^{to inverters.} What makes an oscillator so special? Technically it is a form of amplifier; but we soon find there is more to it than that.

In most general sense, when a voltage or current varies in value about a certain level, we have an oscillatory condition. The variations be of periodic occurrence; indeed, the term oscillation and alternating current are not fundamentally different nature. Most oscillations involve periodically repetitive waves, symmetrically displaced about the base line. Irregularly spaced waves, and wavetrains made up of excursions of one polarity only, may be considered oscillatory also.

For the purpose of practical electronics, we defined an oscillator as a device which automatically converts direct current power to power in the form of

alternating or pulsating current or voltage. It might appear that the alternator converts dc to ac because its field windings are energized by direct current and alternating current is delivered by its output windings.

A second "conversion" device which cannot qualify under our definition an oscillator, is the amplifier.

What is an Oscillator ?

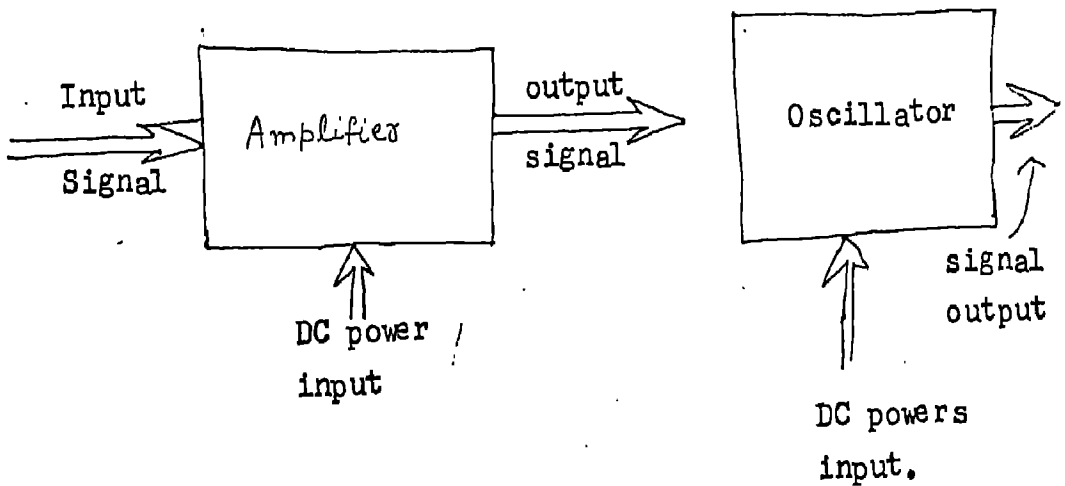
An electronic oscillator may be defined in any one of the following four ways:

1. It is a circuit which converts dc energy into ac energy at a very high frequency.
2. It is an electronic device which is a source of alternating current or voltage having sine, square or sawtooth or pulse shape (wave of short duration).
3. It is a circuit which generates an ac output signal without requiring any externally applied input signal.
4. It is an unstable amplifier, with a positive feedback.

Comparison between an Amplifier and an Oscillator :-

An amplifier produces an output signal whose wave form is similar to the input signal but whose power level is generally high. The additional power is supplied by the external dc source. Hence an amplifier is essentially an energy convertor i.e., it takes energy from the dc power source, (battery) and converts it into ac energy at signal frequency.

The process of energy conversion is controlled by the input signal. If there is no input signal, there will be no energy conversion and hence there is no output signal.



An Oscillator differs from an amplifier in that the Oscillator does not require an external signal either to start or maintain energy conversion process. It keeps producing an output signal so long as the dc power source is connected.

Amplifier increases the amplitude of a signal without affecting the frequency component.

Where as in oscillator, amplifier serves the purpose of imparting energy to the oscillatory circuit to maintain and sustain oscillation.

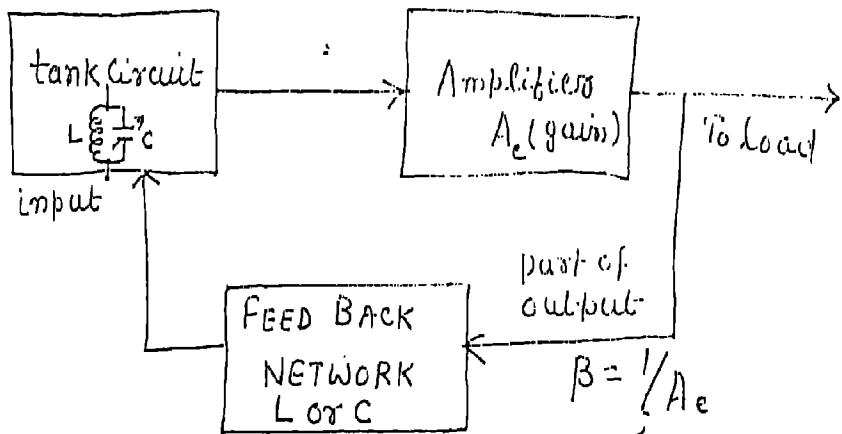
In most general sense an oscillator is an tuned amplifier with proper positive feed back.

Components of an oscillator :-

Essentially there are three basic parts of an oscillator.

1. tank circuit
2. Amplifier

3. feed back network or circuit.



part or fraction of the output of an amplifier is feed back to the input in proper phase so as to act as a positive feed back amplifier.

It should be made clear to the students that a transistor circuit act as an part of a oscillator does not oscillates, it is the tank circuit/any other quartz crystal. Which produces damped oscillations and amplifier substitute the energy to compensate for the losses and maintains the out put undamped.

The Block diagram of an oscillator is shown in Fig.

The transistor used in amplifiers is used to keep the LC circuit oscillating with frequency $F = \frac{1}{2\pi\sqrt{LC}}$

Transistors used in an oscillator circuit does not

that the feedback energy and the input energy of an amplifier be in phase (positive feed back).

Basic principle :-

The parallel LC circuit when employed in an oscillator circuit is called the tank circuit. The inductor and capacitor fix the frequency of oscillation. The principle of operation of a sinusoidal oscillator is quite simple and straight forward. First the tank circuit is excited into oscillations by a surge of current. The ac voltage is feed back to the tank circuit is amplified by the transistor. Part of the amplified (B) is feed back to the input (tank circuit) by either inductive or capacitive coupling to compensate for power losses in the tank circuit which causes the damped oscillations. This regenerative feed back results in a constant amplitude, ac output of the same frequency as that of tank circuit.

Let us assume that an amplifier with gain A and A_F gain with feed back. If B is the fraction of output feed to input than.

$$A_F + = \frac{A}{1 - AB}$$

Now to get infinite gain or output without any input signal.

$$A_F + = \infty \text{ when either } 1 - AB = 0 \text{ or } AB = 1 \text{ or } \beta = \frac{1}{A}$$

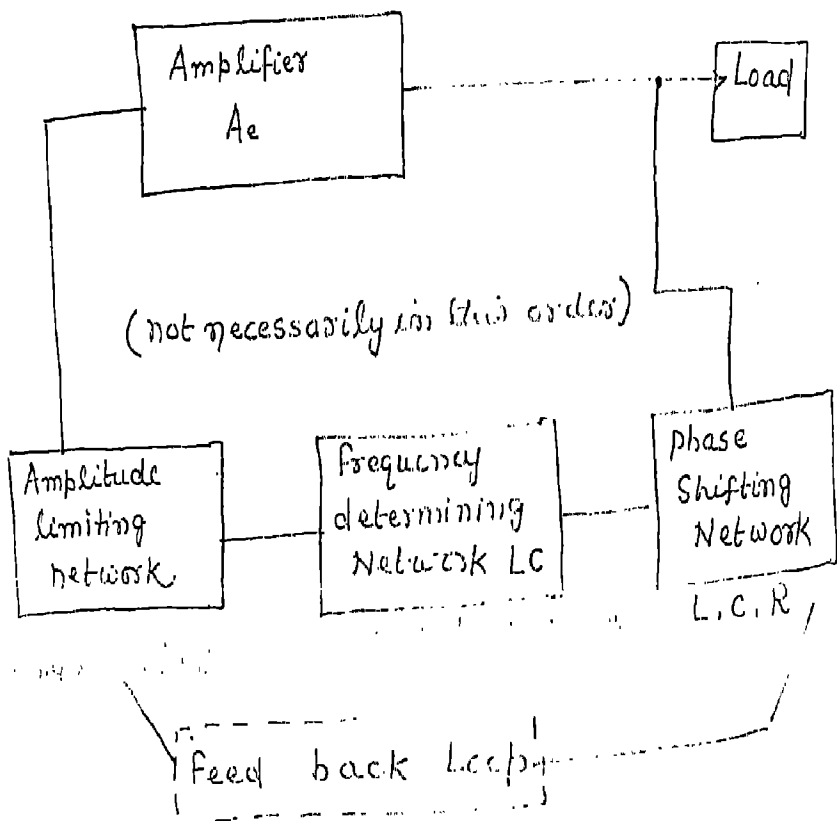
This condition is known as the Barkhausen criterion for self sustaining oscillations in an oscillator circuit.

itself do any oscillations. It is the LC tank circuit that oscillates when a small pulse of high current flows through it. It is the amplifiers that sizes the kick at right moment.

Regardless of its type any oscillator may be divided into three basic elements.

1. The frequency determining network/often called resonator)
2. The amplifier
3. The load or output circuit.

Fundamental oscillator components



The out put power of the amplifier (divided-as it is between the load and the feed back loop) must be sufficiently large to supply both

A second requirement for maintaining oscillation is

Summary- Oscillators

- * Electronic Oscillators generate sinusoidal and non-sinusoidal ac voltages.
- * Oscillators are used in every branch of electronics, such as radio, television, radar, and transmitters, inverters.
- * An LC circuit, may be shock-excited (triggered) into oscillations, but unless the losses of the circuit are replaced, the oscillations are damped and die out.
- * Special arrangements of feed back circuits, usually transistors in conjunctions with coils and capacitors, may supply the energy required to overcome resistance losses in the tank circuit and sustain oscillations.
- * When a transistor is connected so that it has positive or regenerative, feed back it can be used to generate alternating current. As a general rule this type of electronic circuit is called an oscillator. Essentially the transistor is used as an amplifier with part of its output returned in phase to the input.

Points to remember

Semiconductors and transistors :-

1. A semi-conductor has a resistivity between that of a conductor and an insulator. Examples of semiconductors are germanium and silicon.
2. N-type germanium contains donor impurities material having five valence electrons. One of these electrons cannot form an electron pair bond, and is called an excess electron.
3. Common donor materials include arsenic antimony, and boron.
4. P-type germanium contains acceptor impurities material having three valence electrons. Since four valence electrons are needed to complete all adjacent electron pair bonds, a hole is created.
5. A hole can be considered a positive charge which diffuses or drifts through a crystal. The drift of holes constitutes the current.
6. Forward bias of a p-n junction causes a heavy current (flow of majority carriers). Reverse bias causes very low current (flow of minority carriers).
7. Holes constitute the principal current through the p-n-p transistor. Electron constitutes the principal current through the n-p-n transistor.
8. The emitter, base and collector of the transistor are comparable to the cathode, grid

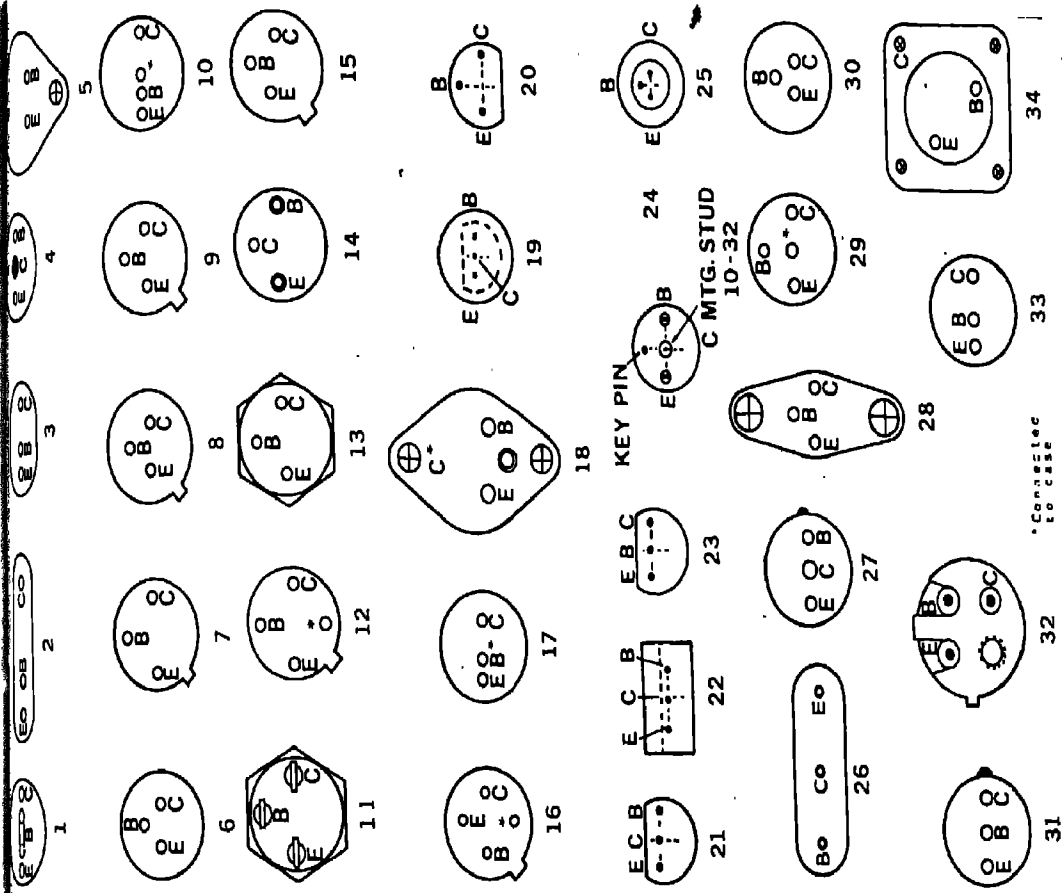
and plate respectively.

9. The emitter base junction is normally biased in the forward (low resistance) direction.
10. The base collector junction is normally biased in the reverse (high resistance) direction.
11. Collector current depends upon the emission of carriers from the emitter-base barriers.
12. Transistor means a voltage transferred across a resistor (Transfer + resistor).
13. Transistor shorts are usually caused by over loading, thus causing the temperature to rise to a value that destroys the junction.
14. Careful attention should be given when soldering transistor in a circuit to avoid overheating the pigtails.
15. When connecting a transistor into a live circuit, the base lead must always be connected first. In disconnecting the transistor from a live circuit, the base lead must be removed last.
16. A low wattage (25 watts) soldering iron should be used while connecting and disconnecting transistor leads.
17. To avoid destruction of a transistor by excessive heat when soldering or unsoldering its leads a low wattage soldering iron (35 watt or less) should be used. To conduct heat away from the transistor, the transistor lead being soldered should be used. To conduct heat away from the transistor, the

Section 8

Transistor Base Diagrams

The base diagrams included in this section are included for the purpose of lead identification, thereby enabling you to determine the correct emitter, base, and collector terminals. The diagrams are also useful in determining substitution feasibility suitability.



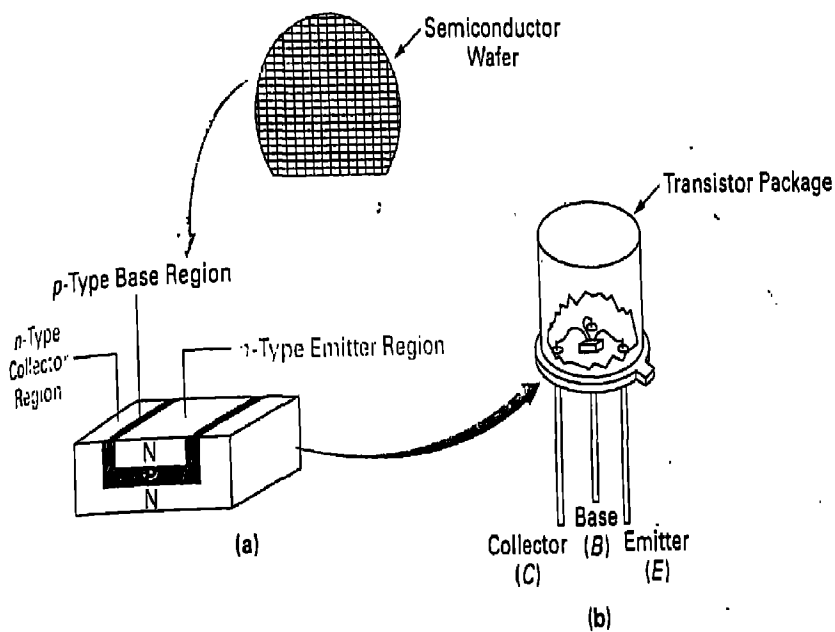
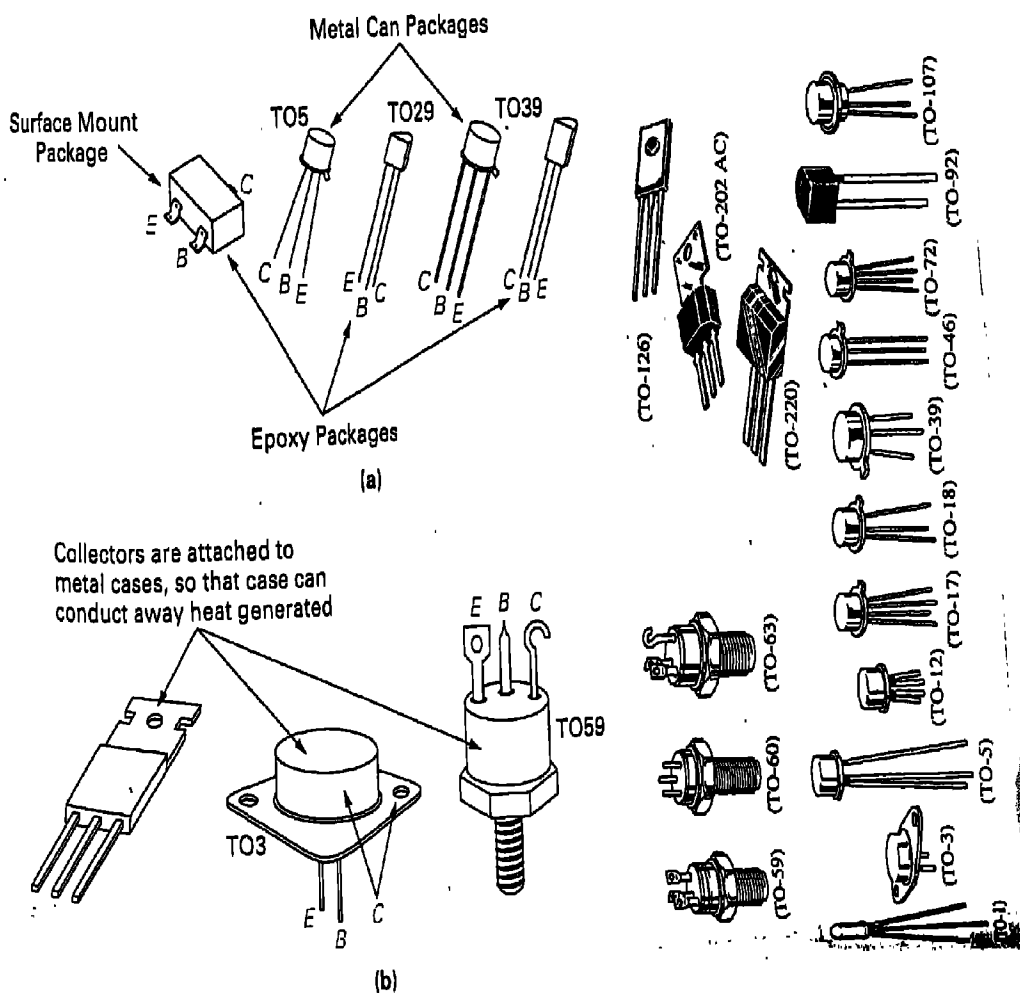


FIGURE Bipolar Junction Transistor Construction and Packaging.

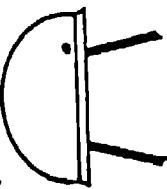


Bipolar Junction Transistor Package Types.
(a) Low-Power. (b) High-Power.



1. Base
2. Emitter
3. Collector

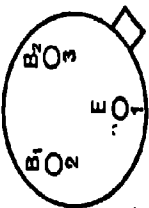
Silicon planar varicap diode
CD 91



Lead Adjacent to dot is cathode

2N 2646/2647

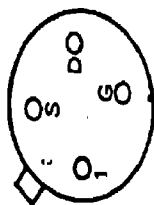
Silicon annular unijunction transistor



Lead 3 Connected to Case

1. Emitter
2. Base-one
3. Base-two

BFW 10/11
N Channel field effect transistor
(Bottom view)



1. Shield lead (Connected to Case)

Maximum dissipation: 500mW
Range values: 2.7V; 3V; 3.3V; 3.6V; 3.9V; 4.3V; 4.7V; 5.1V; 5.4V;
6.2V; 6.8V; 7.5V; 8.2V; 9.1V; 10V; 11V; 12V; 13V; 15V; 16V;
18V; 20V; 22V; 24V; 27V; 30V

BZX 85 series

Tolerance: $\pm 5\%$ Maximum dissipation: 1.3W
Range values: 2.7V; 3.0V; 3.3V; 3.6V; 3.9V; 4.3V; 4.7V; 5.1V;
5.6V; 6.2V; 6.8V

BZX 61 series

Tolerance: $\pm 5\%$ Maximum dissipation: 1.3W
Range values: 4.7V; 5.1V; 5.6V; 6.2V; 6.8V; 7.5V; 8.2V; 9.1V;
10V; 11V; 12V; 13V; 15V; 16V; 18V; 20V; 22V; 24V; 27V; 30V;
33V; 36V; 39V; 43V; 47V; 51V; 56V; 62V; 68V; 75V

1N5333 series

Tolerance: $\pm 5\%$ Maximum dissipation: 5W
Range values: 3.3V; 3.9V; 4.7V; 5.6V; 6.8V; 8.2V; 9.1V; 10V;
12V; 15V; 24V

Transistor and diode encapsulations

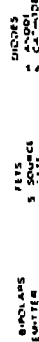
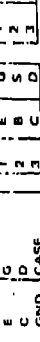
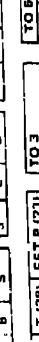
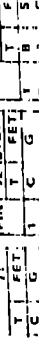
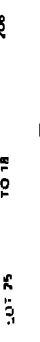
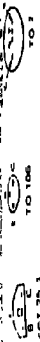
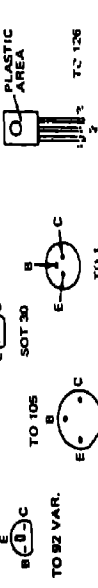
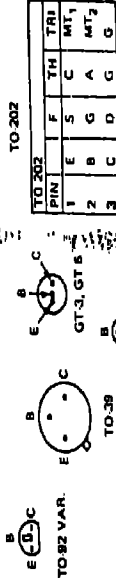


TABLE SHOWING TYPICAL APPLICATIONS OF CAPACITORS

Type.	Approximate capacitance range and tolerance.	Order of maximum working p.d. Volts.	Typical uses.
Tubular rolled paper	2.0-0.0005 μ F 10-20%	1,000	Coupling and decoupling
Metallised paper	2.0-0.004 μ F 25%	400	Decoupling
Rolled paper in metal can	10-0.001 μ F 10-20%	10,000 at least	Coupling, decoupling and smoothing
Polystyrene	0.5 μ F-100 pF $\frac{1}{2}$ -5%	125-500	Resonant circuits, coupling, measuring circuits
Polyester	2.0-0.005 μ F 10-20%	500	Coupling, decoupling and smoothing
Stacked mica	0.01 μ F-50 pF 5-20%	2,000	Radio-frequency coupling and decoupling
Silvered mica	0.1 μ F-10 pF $\frac{1}{2}$ -20%	1,000	Radio-frequency resonant circuits and measuring circuits
Silvered ceramic	0.001 μ F-2 pF 1-20%	350	Radio-frequency by-pass capacitors, radio-frequency circuits
High K ceramic	0.01 μ F-50 pF 20%	350	Used where size is important
Aluminium electrolytic	100-2 μ F 50%	600	Smoothing and decoupling
Tantalum electrolytic	1.000-50 μ F 50%	200-50	Decoupling and by-pass
	200-0.15 μ F 25%	6-150	Decoupling and by-pass, particularly where size and reliability are important as in transistor and printed circuits
Variable capacitors	500-15 pF	2,000	Tuning circuits
Air trimmers	3,000-50 pF 100 s pF	—	Aligning and adjusting tuned circuits

RADIO

[VOL. I

COMPONENTS AND VALVES

Type	Frequency	Inductance	Type of winding	Type of core
Mains transformers	25-100 c/s	1-20 H	Multi-layer	Interleaved, laminated iron or silicon steel
Smoothing chokes	25-200 c/s	1-100 H	Multi-layer	Gapped, laminated iron or silicon steel
Audio-frequency chokes and transformers	20 c/s-15 kc/s	0.1-100 H	Multi-layer and sectionalised	Laminated silicon steel or nickel-iron alloy, gapped if necessary
Radio-frequency coils and chokes	50 kc/s-2 Mc/s 2-10 Mc/s	100 μ H-10 mH 10-50 μ H	Wave wound Close-wound single-layer solenoid	Air, dust iron or ferrite Air, dust iron or ferrite
Wide band transformers; I.F. transformers; line output transformers; deflection coils; pulse transformers	5-200 Mc/s 1 kc/s-10 Mc/s	0.25-10 μ H 0.2 mH-10 H	Single-layer solenoid with spaced turns Multi-layer; may be sectionalised	Air, dust iron or ferrite Magnetic ferrite
Transformers, Filters Blocking oscillator transformers; line output transformers	100 c/s-1 Mc/s 100 c/s-100 kc/s	1 mH-5H 100 mH-10 H	Multi-layer Multi-layer	Ferrite pot Ferrite E and I sections

TABLE SHOWING APPLICATIONS OF VARIOUS TYPES OF RESISTORS

Type.	Dissipation, watts.	Range of values, ohms.	Material.	Finish.	Typical uses.	Tolerances on value.	Notes.
Wire-wound fixed	2-100 Low	1- 100,000 Up to 100,000	Nickel-chrome. Manganin Constantan	Bare or vitreous enamel Varnish	High-power dissipation Meter shunts and multipliers; bridge circuits	1-20% Up to 1%	Resistance does not change with temperature Cheap to manufacture
Carbon fixed	$\frac{1}{16}$ -3	10- 10,000,000	Carbon mix	Varnish or ceramic tube	Radio circuits not requiring great accuracy	5-20%	
High-stability carbon fixed	$\frac{1}{2}$ -2	10- 10,000,000	Carbon on ceramic rod	Varnish	Measuring equipment, balanced circuits	1-5%	—
Wire-wound variable	1-100	Up to 100,000	Nickel-chrome	Various, depends on power rating	Instruments	1-20%	—
Carbon variable	$\frac{1}{2}$ -2	10- 2,000,000	Carbon track	Moulded or metal case	Radio receivers	20%	—

PREFERRED VALUES OF RESISTORS ELECTRONIC COMPONENTS

×A.R. RAMAKRISHNAN

Resistors and capacitors are used in much larger quantities than any other type of component. But have you ever wondered where these are stocked and sold only in 'standard values'. For example, the series of resistors commonly available in the market, say from 1 kilohms, are 1.2k, 1.5k, 1.8k, 2.2k and so on. Resistor manufacturers produce certain fixed values only, and not all possible values. Then, how are these values arrived at? These are neither random numbers nor any fancy numbers but are based on the principle of geometric progression. The numbers given in the example above are more commonly known as the 'preferred values'.

The concept of preferred values (standard values) was suggested by Charles Renard in 1870. He had suggested a similar scheme to reduce

TABLE I
Preferred Values

	E6	E12	E24
1.0	1.0	1.0	1.0
		1.2	1.1
		1.5	1.2
		1.8	1.3
1.5	1.5	1.5	1.5
		1.8	1.6
		2.0	1.8
2.2	2.2	2.2	2.0
		2.4	2.2
		2.7	2.4
		3.0	2.7
3.3	3.3	3.3	3.0
		3.6	3.3
		3.9	3.6
		4.3	3.9
4.7	4.7	4.7	4.3
		5.1	4.7
		5.6	5.1
		6.2	5.6
6.8	6.8	6.8	6.2
		7.5	6.8
		8.2	7.5
		9.1	8.2

the enormous number of cordage sizes used for balloon moorings in the French army. Electronic industries subsequently adapted these series of numbers for ease of production and stock.

Standard E series

By definition, a geometric progression is written as

$$N = a \cdot r^{n-1}$$

where a is the first term, r is the common ratio, and N is the n th term in the geometric series.

Renard suggested a formula for choosing the common ratio ' r '. If ' k ' represents the number of units in a decade (i.e. number of distinctive values in a decade), then the common ratio ' r ' to be chosen for optimum stock is given by

$$r = \sqrt[k]{10} *$$

(k th root of 10)

He also suggested to choose first term $a = 1$.

Therefore, the series becomes

$$N = 1 \times [\sqrt[k]{10}]^{n-1}$$

For example, if it is required to choose three distinctive

3.40

3.48

3.57

3.65

3.74

3.83

3.92

4.02

4.12

4.22

4.32

4.42

4.53

4.64

4.75

4.87

4.99

5.11

5.23

5.36

5.49

5.62

5.76

5.90

6.04

6.19

6.34

6.49

6.65

6.81

6.98

7.15

7.32

7.50

7.67

7.87

8.06

8.25

8.45

8.66

8.87

9.09

9.31

9.53

9.76

values in a decade, substitute $k = 3$ in the above equation.

$$\text{Then } r = \sqrt[3]{10} = 2.2$$

$$\text{Hence } N = 1 \times (2.2)^{n-1}$$

Then values in a decade are 1.0, 2.2 and 4.7. (Note that the values are rounded off.)

We call the above as E3 series in electronic component standards, denoting three preferred values in a decade.

The E3 series will be 1.0, 2.2, 4.7, 10, 22, 47, ... and so on in the subsequent decades.

Other 'preferred value' series are E6, E12, E24, E48 and E96. Applying the same principles, the series and their decade values are shown in Table I.

Manufacturers normally choose one E-series and produce components accordingly. Usually, resistors are available in E12 and E24 series, capacitors in E6 and E12 series (electrolytic types in

E6 and others in E12) and potentiometers in E3 series. Generally, 4 series onwards are used only for precision components.

Power Supplies - Lab

Identification of standard components used in radio circuits by means of color coding has been adopted for some time by the Radio Manufacturers Association. Many of these components find use in industrial electronic circuits, such as amplifiers, time delays, and controls. Among the items thus coded are resistors of 2-watt rating or under and small molded mica capacitors. Larger resistors are identified by the resistance value and wattage rating marked on the body or support. Larger capacitors are similarly marked with the capacitance and voltage rating. The numerical values of the different colors are given in Fig. 1.

COLOR	SIGNIFICANT FIGURE	MULTIPLYING FACTOR
Black	0	1
Brown	1	10
Red	2	100
Orange	3	1,000
Yellow	4	10,000
Green	5	100,000
Blue	6	1,000,000
Violet	7	10,000,000
Gray	8	100,000,000
White	9	1,000,000,000
Gold	5% tolerance	0.05
Silver	10% tolerance	0.10
No color	20% tolerance	0.20

Fig. 1 -- RMA Resistor Color Code

Several systems of marking the color have been used to indicate the resistance value in ohms. Three of the more common methods used are illustrated in Fig. 2.

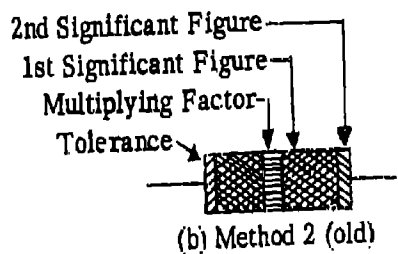
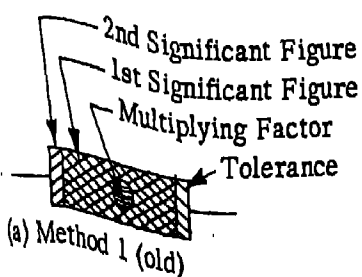
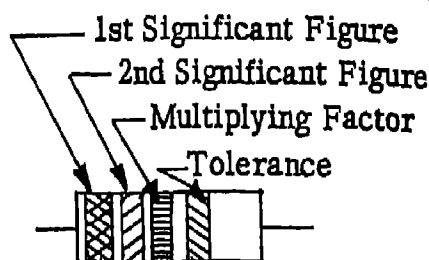


Fig. 2 -- Methods of Color Coding Resistors (continued on page 2)

ELECTRONICS

(Figure 2 continued from page 1)

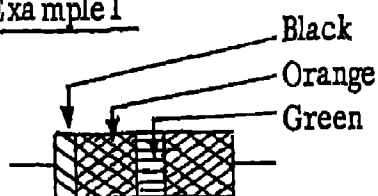


(c) Method 3 (new)

Fig. 2 -- Methods of Color Coding Resistors

In Figs. 2a and 2b the body color indicates the first figure of the ohmic value of resistor, the end color indicates the second figure, and the band or dot at the end of the resistor indicates the number of zeros following the first two figures.

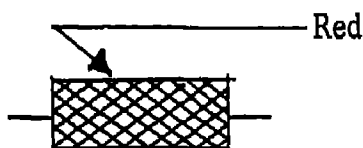
Example I



Body - Orange - Indicates 1st Fig. = 3
End - Black - Indicates 2nd Fig. = 0
Dot or Band - Green - Multiplying Factor:
100,000
Resistance = 3,000,000 ohms

If no gold or silver band is on the resistor, the actual value may vary 20% above below the value indicated by the first three colors. In the case of the first example the ohmic value may vary 2,400,000 to 3,600,000 ohms.

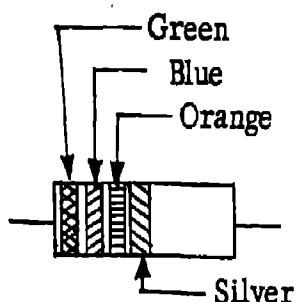
Example II



Body - Red = 2
End - Red = 2
Dot or Band - Red = 100
No tolerance Color = 20%
Resistance = 2200 ohms plus or minus 4%

A more recent method of coding resistors is illustrated in Fig. 2c. The ohmic value of the resistor is indicated by bands of color. The first band indicates the 1st figure, the second band indicates the 2nd figure, the 3rd indicates the multiplying factor, the 4th indicates the tolerance.

Example III



Green - 1st Fig. = 5
Blue - 2nd Fig. = 6
Orange - Multiplying Factor = 1000
Silver - Tolerance = 10%
Resistance = 56,000 ohms plus or minus 10%

Semiconductor devices numbering System

From the time semiconductor engineering came to existence several numbering systems were adopted by different countries. However, the accepted numbering system is that announced by production standardisation authority in Belgium. According to this system of numbering semiconductor devices:

1. Every semiconductor device is numbered by five alpha-numeric symbols, comprising either two letters and three numbers (e.g. BF 194) or three letters and two numbers (e.g. BFX63) when two numbers are included in the symbol (e.g. BFX65), the device is intended for industrial and professional equipment. When the symbol contains three numbers (e.g. BF194), the device is intended for entertainment or consumer equipment.
2. The first letter indicates the nature of Semiconductor material, for example:
A = germanium
B = Silicon
C = gallium arsenide
R = compound material (e.g. cadmium Sulphide).

Thus AC 125 is a germanium transistor whereas BC 149 is a silicon transistor.

3. The second letter indicates the device and circuit function:

A = diode; B = variable capacitance diode

C = A.F. low powered transistor D = A.F. power

transistor.

E = Tunnel diode, F = H.F. low power transistor.

G = multiple device H = Magnetic sensitive diode.

K = Hall effect device

L = H.F. power transistor

M = Hall-effect modulator

P = Radiation sensitive diode

Q = Radiation generating diode

R = Thyristor (SCR or triac)

S = Low power switching transistor

T = Thyristor power

U = power switching transistor

X = diode, multiplier

Y = power device

Z = Zener diode

Data Sheet for Transistors and Diodes

Nomenclature: Two letters followed by a Serial number.

The first letter gives an indication of the Semiconductor material.

A - Germanium

B - Silicon

The Second letter primarily indicates the main application.

A - Detection device (Used in demodulation) e.g. AA119

B - Variable Capacitance diode (Varactor diode) e.g. BB1047

C - For audio frequency Applications e.g. BC148, AC126..

D - Power amplifier transistors for AF amplification
e.g. AD149, BD181

F - Transistor for RF application, e.g. AF114, BF194

Y - Rectifying diode e.g. BY126, BY128

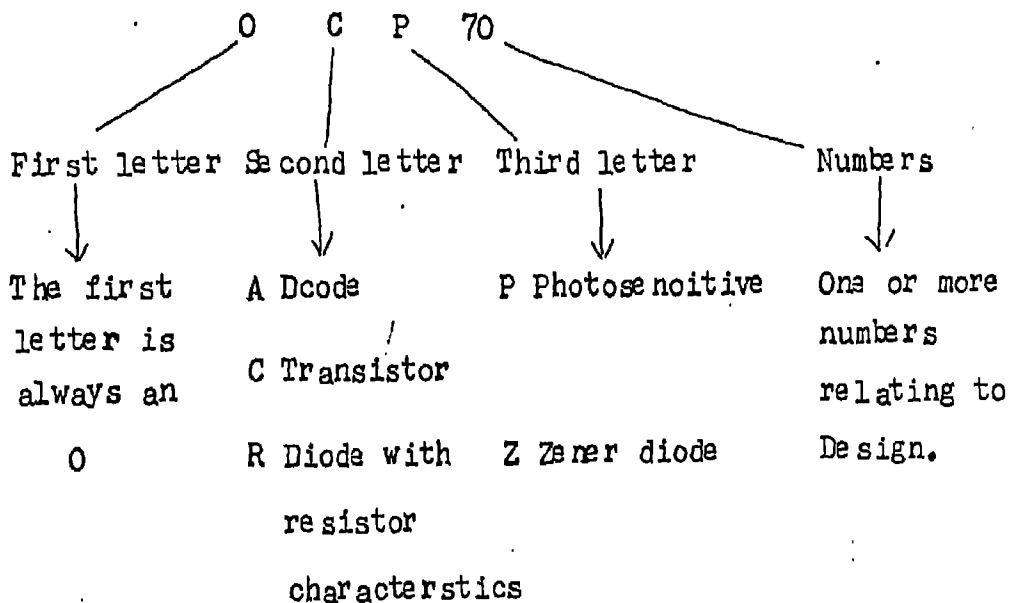
Z - Zener diode, reference Voltage e.g. BZ148,

2N - Two junctions e.g. 2N3055, 2N2222

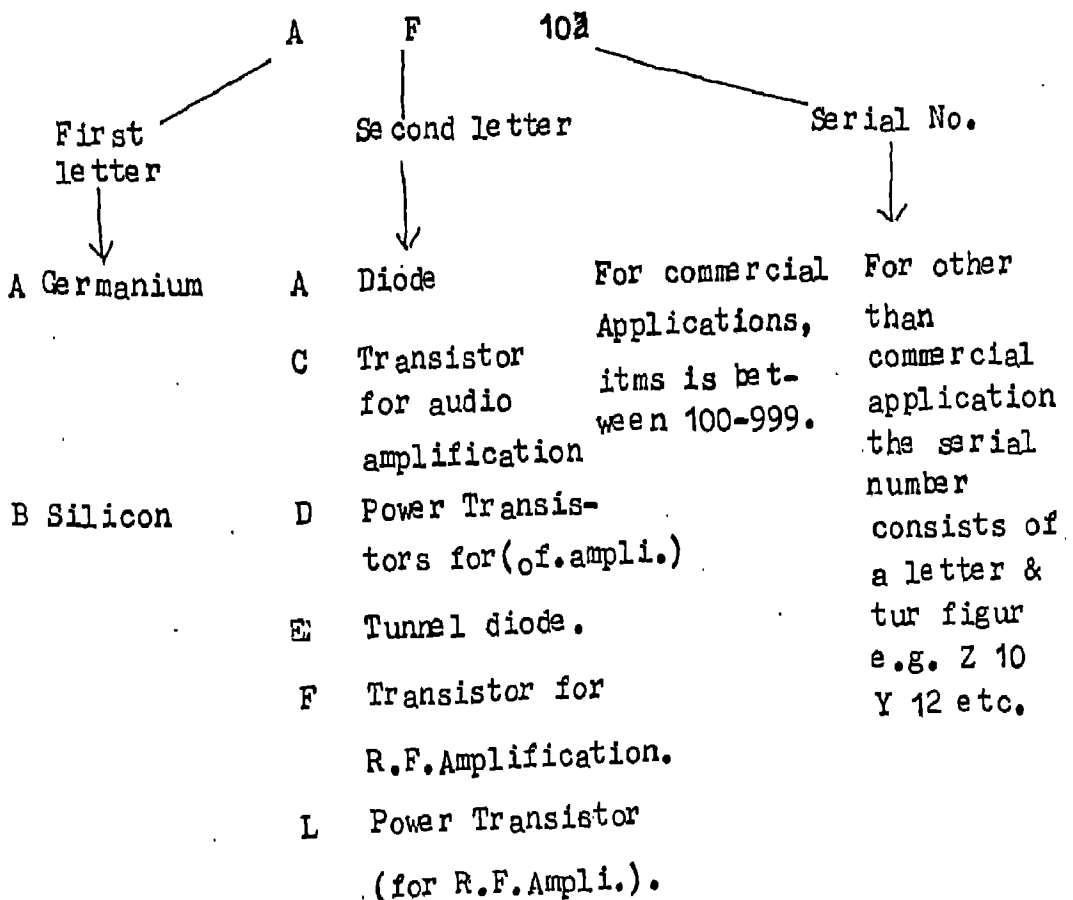
1N - one junction, e.g. 1N4001

Transistor Designation Systems

- a) the old European code
- b) the new European code
- a) The Old European Code



b) The New European Code



P Photosensitive

 Semiconductor

S Switching Transistors

T Thyristor, shockley

 diode controlled

 rectifier

U Power switching

 transistor

Y Power diode

Z Zener diode

A T Z 10

Device Nomenclature

#European Nomenclature

#Japanese Nomenclature

The Part number is an essential part of the device identification process. Depending on where the parts are made the part numbers will mean something different. For example, The European nomenclature is different from the Japanese nomenclature which is different from the North American nomenclature. Parts of each of these nomenclatures means something different. They represent information that is important to the way the device is used. For example, what material the device is made out of, applications it can be used for, and a series of number that distinguish that part from all others so one can find device specifications and parts that may be compatible with the part that is being looked up.

European Semiconductor Numbering System

BFR90

```

|| | Third, Fourth, Fifth Character (Serial Code)
||   Y## Industrial service (No letter Z)
||   ## is a W## Registration number from 10_99
||   100- Device for consumer or entertainment
||   999 use.
||
||
||

```

First letter---||---Second Letter (Type)
(Material)

A Germanium

A Low Power diode,
voltage-variable capacitor

B Silicon

B Varicap

C Compound Materials
such as cadmium
sulfide or gallium
arsenide used in
semiconductor devices.
(energy-gap band of
1.3 or more eV.)

C Small-signal audio transistor

D Materials with an
energy gap of less

D Audio power transistor

<http://zeus.cedcc.psu.edu/semi/nomenc.html>

7/12/200

than 0.6 eV such as
Indium antimonide.

- R** Radiation detectors,
photo-conductive cells,
Hall-effect generators
and so on
- E** tunnel diode
- F** Small-signal RF transistor
- G** Miscellaneous
- H** Field Probe
- K** Hall Generator
- L** RF-Power transistor
- M** Hall modulators and multipliers
- P** Photo diode, photo-resistor
,photo-conductive cell(LDR),
Radiation device.
- R** Low-power controlled rectifier
- S** Low-power switching transistor
- T** Breakdown devices,high-power
controlled rectifier,Schottky
diode, Thyristor,pnpn diodes.
- U** High-powered switching transistor
- X** Multiplier diode
- Y** High-power rectifier(diode)
- Z** Zener diode

Japanese Nomenclature

i	ii	iii	iv	v
2	S	C	S2D	A

- i) Kind of device, indicating the number of effective electrical connections minus one.
- ii) For a semiconductor registered with the EIAJ this letter is always an S.
- iii) Third letter designates the polarity and application, as follows:
- A** PNP transistor, high-frequency
 - B** PNP transistor, low-frequency
 - C** NPN transistor, high-frequency
 - D** NPN transistor, low-frequency
 - E** P-gate thyristor
 - F** N-gate thyristor
 - H** N-base unijunction transistor

J P-channel FET
N N-channel FET
M Bi-directional triode thyristor

- iv) These figures designate the order of application for EIAJ registration, starting with 11.
- v) This letter indicates the level of improvement. An improved device may be used in place of a previous-generation device, but not necessarily the other way around.



Return to Semiconductor Page

Please direct questions, comments or problems to the [Webmaster](#)

Last modified: Mon Sep 25 14:56:53 EDT 1995

Experiment 1

Electronic Familiarity

Identification of Electronic Components

Objective: The object of this lab is to examine and identify several electronic devices.

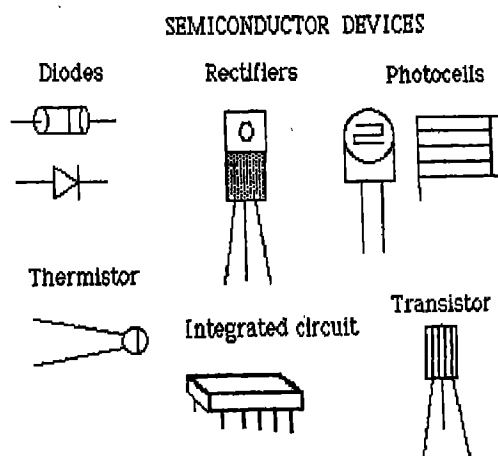
Applications:

Many individuals work with a variety of electronic components during a typical work day. Scientists, engineers and repair technicians all must be able to recognize a variety of components by sight in order to accomplish their jobs.

Time: One half hour

Introduction:

Electronic devices and components of modern electrical circuits take many appearances. Looking into a radio or calculator to see the working parts will baffle most people. For you to have a better understanding of electronic devices and components, you need to be able to recognize some of the more common parts. Because of their great variety of colors, shape and sizes it is possible to include only a few diagrams in this lab. Catalogues from Radio Shack, Mouser, or Newark are good references for pictures.



Materials and Supplies:

microscope and/or stereoscope

hand held magnifier

electrical meters (voltmeters, ammeters, ohmmeters, or multimeters) AC/DC power source

samples of electronic components from old radios, T.V.'s, calculators including:

samples of wire (10 cm)

coaxial cable

capacitors

choke coils

diodes

fuses

integrated circuits

flashlight bulbs

light emitting diodes (LED)

photocells

transistors

resistors

semiconductor rectifiers

zener diodes

solder

thermistors

transformers

potentiometer

micro-chip

vacuum tube

photoresistors

General Safety Guidelines:

* Students should be careful of sharp edges while handling the small electronic devices.

Procedure:

1. Spread some of the electronic devices on a piece of paper on your table or desk.
 2. With the naked eye observe the appearance and shape of the devices.
 3. Examine each device with a hand lens magnifier.
 4. Use a microscope or stereoscope to look for details, especially on the transparent
- <http://matse1.mse.uiuc.edu/~tw/sc/a.html>

devices.

5. In your notebook make a rough sketch of the devices and label each diagram.

Questions:

1. Which devices can be identified as metal/nonmetal conductors?
2. Which devices include semiconductor materials?
3. Which devices will resist the flow of electrons?
4. Which devices will allow the electron flow in one direction only?
5. Identify the uses for five of the examined devices.
6. Identify five devices used in microelectronics applications.

Teacher Notes:

* Teacher preparation time is about 10 minutes.

* The lab time depends on the number of devices being observed.

* A "junk box" may contain many of these items. Check with a local electronic repair shop for discarded devices or have students bring old broken or discarded parts.

* To help students identify the devices make electronic catalogs available. (Radio Shack, Mouser Electronics, etc.)

* The teacher may want to break open some of the devices with pliers or a hammer to help students see what is inside.

Answers to Questions:

1. Wire, cable, choke coils, solder, flashlight bulbs
2. Diodes, IC chips, LED's, photocells, transistors, thermistors
3. All materials resist the electron flow to some degree. Semiconductors and insulators have more resistance than metals.
4. Diodes, LED's, rectifiers
5. All solid state radios, TV's, printed circuits, calculators, computers (see glossary for more help)
6. Integrated circuit (IC chip), diodes, transistors, photocells, LED's

Next Lab

Experiment 2

Hot and Cold

Temperature and Resistance of Electronic Materials

Objective: The object of this lab is to show how temperature affects the conductivity (resistance) in various electrical materials and devices.

Review of Scientific Principles:

Heat: As heat is applied to a crystalline solid, we say "it gets hotter"; meaning the temperature increases. On the atomic level, the kinetic energy of the atoms has increased which means the atoms are moving faster. However, in a crystalline solid, the atomic movement is limited to vibration around stable lattice positions. As the temperature increases, the atoms vibrate at a greater amplitude and move farther from their stable lattice positions. This motion has a negative effect on the ability of the material to conduct an electric current, causing it to have a greater electrical resistance.

Metals: In a metal, the valence electrons are thought of as being shared by all the positive ions. Therefore, the electrons are free to move throughout the crystalline lattice. The electrons move randomly throughout the crystal, until an electric field is applied to the material. Then the electric field forces the electrons to move in a direction opposite to the field. Actually, the electrons still move somewhat randomly, but with a superimposed "drift". This produces current. As the temperature increases, the positive ions in the crystal vibrate more, and more collisions occur between the valence electrons and the vibrating ions. These collisions hinder the "drift" motion of the valence electrons, thus reducing the current. In summary, for a metal, an increase in temperature causes an increase in resistance.

Semiconductors: In a semiconductor, at 0 K, valence electrons are in filled energy levels (bonds are formed by electron pairs filling the energy levels). They do not respond to an applied electric field to produce current flow. In the presence of an electric field, the electron motion is still random; no net motion in one direction occurs (no current flows). These filled energy levels, which the valence electrons occupy, form the valence band. In order for current to flow, electrons must move from the filled valence band to the empty conduction band. To make this move requires energy, which can be in the form of heat. (Important: the electrons do not move from a "place" in the crystal called the valence band to another "place" called the conduction band. The electrons have the energy associated with the valence band and acquire enough energy to have the energy associated with the conduction band. An energy change occurs, not a position change.) At room temperature, many electrons will have the energy needed to jump to the conduction band. As one electron moves out of the valence band and into the conduction band, a hole (vacancy) is produced in the valence band. Both the electrons in the conduction band and the corresponding holes in the valence band are considered charge carriers. When an electric field is applied to the material, these electrons and holes "drift". The electrons in the conduction band drift in the direction opposite to the applied field, and the holes drift in the same direction as the applied field. Thus, current is produced. As the temperature of the material is increased, more valence electrons acquire sufficient energy to move to the conduction band (producing holes), so more current flows. It is still true that as the temperature is increased, the atoms vibrate more and cause more collisions with the drifting electrons. However, this opposing effect is negligible, compared to the increase in charge carriers.

Applications:

Different types of materials respond differently to temperature changes. A computer engineer designing a circuit must be able to predict if the conductivity of each material in the device will be

within an acceptable range over the expected temperature range of operation of the device.

Time: One hour

Materials and Supplies:

heat source for boiling water (hot plate preferred)

5 beakers for water baths

thermometer

choke coils or resistance spools

germanium diodes

thermistors

light emitting diodes (LEDs)

carbon resistors

glass rod (5 cm)

2 digital multimeters or a voltmeter and milliammeter

wire connectors with alligator clips

power supply (0 to 12 volts DC)

General Safety Guidelines:

- * The heat source could cause burns. Exercise caution.
- * Be careful of electrical shock.
- * Handle meters and samples with care.
- * Wear safety glasses.

Procedure:

1. Set up five water baths of about 100-200 ml of water in beakers at the following temperatures: boiling, 75 ° C, 50 ° C, 25 ° C, and ice water.
2. Measure the temperature of each bath with a thermometer, thermistor, or thermocouple.
3. For measuring the resistance of the device (choke or resistance coil) set up the multimeter to read ohms and connect as in the following diagram.
<http://matse1.mse.uiuc.edu/~tw/sc/b.html>



4. Carefully holding on to the lead wires so as not to burn the fingers, immerse the coil into the boiling water bath, until a stable value is received (for about one minute) and record the resistance in the data table.
5. Follow the same procedure in the 75° , 50° , 25° and ice water.
6. Remove the coil and attach another device to the meter, following the same procedure for measuring the resistance.

Data and Analysis:

CONDITION	TEMP. C	CHOKE COIL		GERMANIUM DIODE		THERMISTOR			
		$\circ$	R	$\circ$	R	$\circ$	R	$\circ$	R
Boiling water	100								
Hot water	75								
Warm water	50								
Room temp	25								
Ice water	0								

For each device, draw a graph, with the temperature (x-axis) vs. resistance (y-axis).

Questions:

1. Which samples had a change in resistance as the temperature increased? What direction was that change?
 2. As their temperatures increased, what happened to the resistance of the conductors, the semiconductors? Does the change seem to be linear?
 3. Did any of the samples follow the general guidelines explained in the introduction to the lab? Explain.
 4. Describe the motion of the atoms or ions in a crystalline solid as the temperature increases.
 5. What causes electrons to "drift"?
 6. Describe the electron motion while current is flowing.
 7. Explain how increasing the temperature of a semiconductor decreases the
- <http://matse1.mse.uiuc.edu/~tw/sc/b.html>

resistance.

8. Explain how increasing the temperature of a metal increases its resistance.

Extension:

For the thermistor, plot $1/T$ (K^{-1}) on the x-axis and $\ln R$ (natural log of the value of the resistance in ohms). This graph is a straight line. The equation of this line is:

$$\ln R = (E_{\text{gap}} / 2k) \times 1/T + \ln R_0$$

where:

$$k = 8.62 \times 10^{-5} \text{ eV/K (Boltzman's constant)}$$

E_{gap} = band gap energy (the difference in energy between the conduction and valence bands) in electron volts.

Determine the slope of the line from the graph. $(E_{\text{gap}} / 2k) =$ the slope, from the equation. Solve this equation for E_{gap} .

Teacher Notes:

*Teacher preparation time is about 30 minutes.

* Resistance coils could be used instead of a choke coil. (Short pieces of wire do not show enough resistance.)

* Other kinds of wire besides copper could be tried.

* Connector leads to devices could be extended by soldering on short lengths of wire.

* The carbon device should lose only a small percentage of its room temperature resistance, but semiconductor devices should go up appreciably at low temperature.

* As an example of a nonconductor, a length of glass rod could be tested.

* Use a Type K thermocouple for lower temperatures in conjunction with some digital multimeters.

* Thermistor probes are available from Vernier.

* The teacher should demonstrate proper hookups of meters and devices.

* Diode results work best if the temperature is taken from the boiling water and the ice water.

* For the extension activity, using the sample data, the value of $E_{\text{gap}} = 0.6 \text{ eV}$.

Answers to Questions:

1. All the devices changed their resistance as the temperature changed. The

resistance of the choke coil (which is copper wire) increased as the temperature increased. The resistance of the diode and the thermistor (which are made of semiconductor material) decreased as the temperature increased.

2. The resistance of the conductor increased linearly. The resistance of the semiconductor decreased, but not linearly.

3. Student answers will vary. The devices do react as theoretically predicted.

4. As the temperature increases, the atoms or ions vibrate with greater amplitude around their stable lattice positions.

5. When an electric field is applied, the electrons are forced to drift.

6. The electrons are moving randomly and drifting in the opposite direction of the applied electric field.

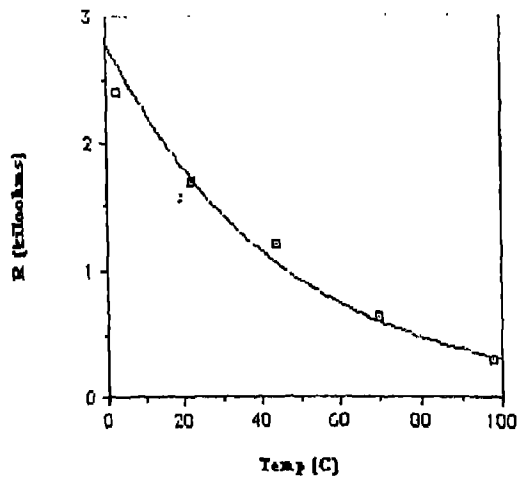
7. As the temperature increases, more electrons have the energy needed to move to the conduction band (more charge carriers means more current).

8. Greater amplitude of vibration of the ions in the lattice cause more collisions with the valence electrons, which decreases the drift velocity.

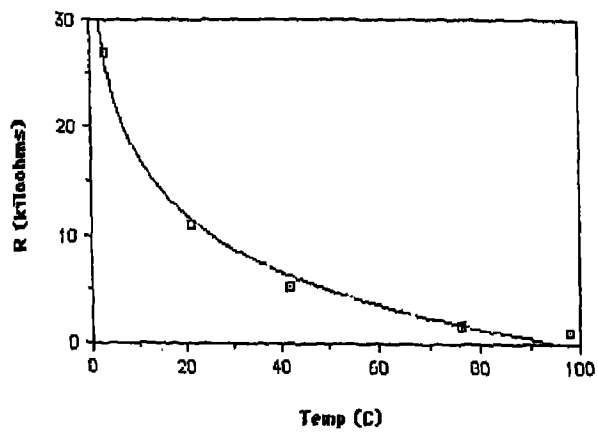
Sample Data and Analysis:

Condition	Temp °C	Choke Coil		Germanium Diode		Thermistor			
		°	R ω	°	R k ω	°	R k ω	°	R k ω
Boiling Water	100	97	44	98	0.29	93	1.0		
Hot Water	75	77	41	70	0.63	76	1.7		
Warm Water	50	51	37	44	1.2	42	5.2		
Room Temp	25	22	33	22	1.7	21	11		
Ice Water	0	3.5	31	2.8	2.4	3	27		

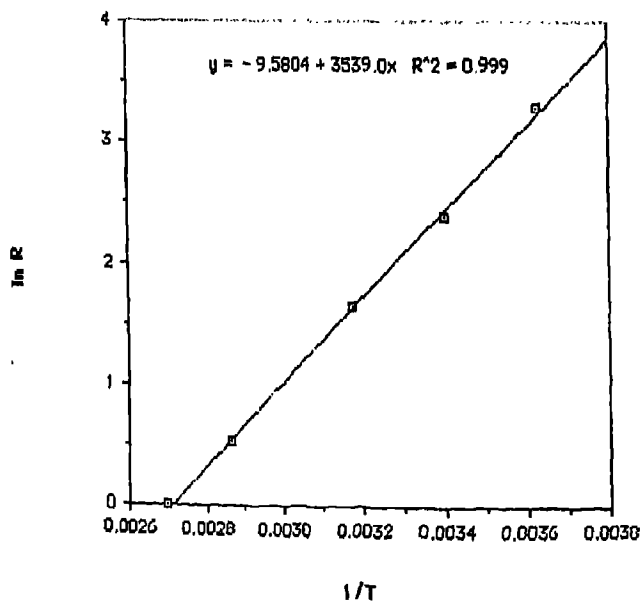
Ge diode



Thermistor



Thermistor



Next Lab

Experiment 3

Let There Be Light

Photoconductive Properties of Semiconductors

Objective: The objective of this lab is to quantitatively determine how the electrical resistance of a cadmium sulfide photocell varies as a function of light intensity (distance).

Review of Scientific Principles:

Semiconductors often have the ability to respond to various forms of electromagnetic radiation. Silicon, germanium, gallium arsenide and cadmium sulfide are materials that can have opto-electronic effects, which means their electrical properties are responsive to light. This is due to the energy inherent in light radiation. Absorbing this energy can make some of the valence band electrons move to the conduction band. As a result, the conduction characteristics of the material change. In this lab, you will explore a cadmium sulfide "photoresistor" as it is exposed to various intensities and colors of light. You will be looking for possible connections between light intensity or energy and conductivity.

Applications:

Opto-electronic devices such as photo-resistors, photo-diodes, and photo-transistors are being used more each year. These devices are commonly found in switches for outdoor lighting, on-off switches for pole lights and security systems. The "electric eye" can be used for a dimmer switch on the headlights of a car. The photo-resistor is also an important device in fiber optic communications. Photo-laser diodes are often found in the classroom in the form of pen sized laser pointers.

Time: One hour

Materials and Supplies:

cardboard tube (approximately one meter long and 3 to 5 cm diameter)

meter stick

black electrical tape and duct tape

cadmium sulfide photocell

light bulbs- white, screw mini-base, 3 to 12 volt (Radio Shack)

miniature lamp socket- screw base

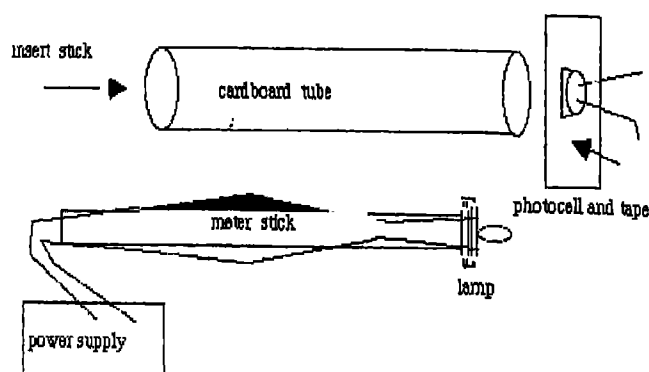
voltage supply (0 to 12 volts DC)

digital multimeter or ohmmeter

wire connectors

General Safety Guidelines:

- * The leads of the photocell and the light bulb glass are fragile, handle carefully.
- * Avoid electrical shock.



Experimental Set-up

Procedure:

Equipment construction:

1. Obtain a cardboard tube from wrapping paper (or make a roll from cardboard into about a 60 to 70 centimeter tube with about a 5 cm diameter and tape so it will hold its cylindrical shape). The diameter must be large enough to allow the lamp socket to move through the tube while not allowing light to get in around the socket.
2. Press the electrodes of the CdS cell through a piece of duct tape large enough to cover the open end of the tube so that the cell is inside the tube and the electrodes are on the outside of the tube. (Several small pieces of black electrical tape work well.)
3. Place this tape with the cell over one end of the tube and fold the tape onto the tube so that no light can get into that end.
4. Connect one end of each of the wires to the lamp socket by bringing the wire up through the holes in the base of the socket and securing under the screw.
5. Tape the socket to the end of the meter stick so that the bulb extends away from the end of the stick.
6. Tape the wires along the meter stick allowing the wire to extend past stick.

7. Insert the socket end of the meter stick into the open end of the cardboard tube and slide the socket toward the CdS cell at the opposite end. The socket should slide freely, but not allow light to go past into the tube. If the space around the socket is too large, wrap some layers of tape on the outside of the socket.
8. Withdraw the socket, place a bulb in the socket and connect the wires to the power supply or batteries. Use the proper voltage for the light bulb being used.
9. Make sure the bulb works, then turn it off.

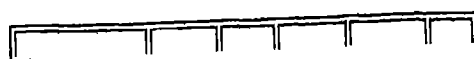
Collecting data:

10. Connect the multimeter to the CdS photocell, and set to measure resistance in kilohms. There should be a reading on the meter.
11. With the light off, slide the bulb into the tube until it just touches the CdS cell.
12. Take a resistance reading and record in the data table for a dark measurement.
13. Turn the light on and immediately take a reading for 0 cm from the cell.
14. Pull the meter stick and light out of the tube a distance of 10 cm and take another reading.
15. Continue pulling the light out and taking readings for each 10 cm until reaching about 60 or 70 cm.
16. Turn the light off and carefully peel the duct tape and photo cell from the end of the tube in a way that it can be used again.
17. Using a small piece of colored filter supplied by your teacher, cover the CdS cell and press the filter against the sticky tape to hold it in position over the cell.
18. Push the light into the tube and again take readings as in steps 11 through 16.
19. Repeat with the other colored filters.

Video Clip of experiment

Data and Analysis:

Record the observed resistance values for each color at the given distances.



Bulb Color	white	blue	green	yellow	red
Distance					
0 cm					
10 cm					
20 cm					
30 cm					
40 cm					
50 cm					
60 cm					
70 cm					

For each light, graph the resistance on the vertical axis and the distance on the horizontal axis. (Use one graph if the sizes of the resistances are comparable.)

Questions:

1. What is the general shape of the graph?
2. What happens to the resistance as the distance increases (as the light intensity goes down)?
3. What happens to the resistance as the color (energy) changes, assuming a fixed distance, such as 20 cm?
4. Can you provide an explanation for either of the above phenomena?

Teacher Notes:

*Teacher preparation time is approximately 30 minutes.

* Photocells and 6 volt miniature lights are available at Radio Shack.

* Filters of different colors may not allow the same amount of light intensity to pass so be careful in comparing results from different colors.

* Time may dictate whether all these colors can be done by all the groups. Perhaps different groups could be assigned different colors and class data collected. The experiment may be done as a demonstration if supplies are limited.

* The light intensity is inversely proportional to the square of the distance, and the resistance is inversely proportional to the intensity of the light.

* An extension exercise could be to have the students work on an electric eye project.

Actual Experimental Data:

all data in kilohms

Distance	white	blue	green	yellow	red
dark	70	70.3	71.6	70.1	70.9
0 cm	.158	.393	.415	.122	.198
10 cm	.671	4.78	7.07	.978	1.54
20 cm	1.98	13.5	17.7	2.56	4.23
30 cm	3.61	23.5	27.9	4.76	7.55
40 cm	5.55	31.9	37	7.28	10.9
50	7.82	39.6	43.3	10.3	14.5
60 cm	9.5	45.9	47.2	12.8	17.3

Analysis with Answers:

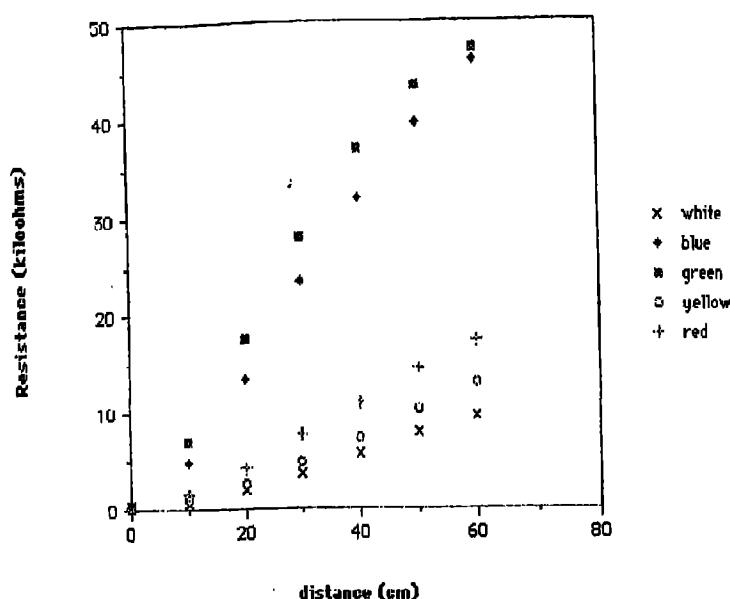
1. What is the general shape of the graph? *Exponential; the intensity of the light is inversely proportional to the square of the distance, so the graph should resemble a parabola ($I = k * D^2$). Other factors can also influence the shape of the graph. It is not expected that the relationships will follow a perfect pattern.*

2. What happens to the resistance, in general, as the distance increases, that is as the intensity goes down? *The resistance becomes larger.*

3. What happens to the resistance as the color (energy) changes, assuming a fixed distance, such as 20 cm?

4. Can you provide an explanation for either of the above phenomena? *When the intensity of the white light goes down, fewer valence electrons are promoted into the conduction band. As a result, the resistance of the photocell increases. The variation of measured resistance because of different colors of light hitting the photoresistor may be dependent on several factors. One factor is that the intensity of the light passing through the filter may vary because of the optical*

density and thickness of the material. Also, each color of light has a specific energy ($E = hf$). Therefore, the DMM readings for the colored light may differ from white light.



Extension Activities:

Experiment Design and Application Project

The Electric Eye

In the photoconductivity lab, where a cadmium sulfide photocell was used, you used only visible (optical) photon energy sources. That is, only light bulbs were used. Can you extend this laboratory concept by using non-visible energy sources? (For example, "black lights" or ultraviolet (UV) bulbs are now quite common. They could extend your energies even higher than your blue light did. Infrared (IR) diodes (available at Radio Shack) could be used to extend you energies to lower values.

Using these suggestions as a starting point, can you design another experiment where data can be taken for other kinds of electromagnetic radiation? How will you know if an infrared diode is working, if you cannot see it? Will you test other kinds of photocells besides CdS? What kinds of things do you hope to discover about these materials? Do all photocells respond to electromagnetic radiation in exactly the same way? Can you plot the curves? Can you explain why? Which devices would make the best "electric eyes"? Can you design a simple electric eye circuit and test it under actual conditions?

Today electric eyes are all around us on farms for turning on outside lights, on automatic street lights and on road constructions sites (for night time flashing lights).

Thermal Variation of the Resistivity of a CdS Photocell

Under constant lighting conditions, such as ordinary daylight, vary the temperature of the CdS photocell as much as possible. Using the DMM, measure its resistance for each thermal environment from low to high temperatures. What is the relationship between temperature and resistivity in the photocell?

Next Lab

Semiconductor Contents

Experiment 4

What is Ohmic?

I-V Characteristics of a Diode vs. a Resistor

Objective: The object of this experiment is to compare the I-V characteristics of a diode with those of a resistor. By measuring the voltage drop across the diode or resistor as the current is varied, the student will discover the relationship between the current and the voltage.

Time: 40-50 minutes

Review of Scientific Principles:

Requirements: To make a current flow through a material, three requirements must be met.

1) An electric field must exist; 2) charge carriers must be present in the material; and 3) the charge carriers must be mobile. To establish an electric field, a voltage is applied to the circuit. The charge carriers are the valence electrons in a conductor, or the electrons in the conduction band and the holes in the valence band of a semiconductor or insulator. The mobility is dependent on the crystal structure and the temperature.

Conductor: For a conductor, such as a metal, the valence electrons occupy partially filled energy levels to form a valence band. The crystal structure of a metal allows the valence electrons in the valence band to move freely through the crystal. However, as the temperature increases, the atoms vibrate with greater amplitude, and move far enough from their equilibrium positions to interfere with the travel of the electrons. Only near absolute zero is the mobility at its maximum value.

Semiconductor: For a semiconductor or insulator, the valence electrons occupy a filled valence band. Electrons must move from the valence band to the conduction band (leaving holes, vacancies, in the valence band). Both the electrons in the conduction band and the holes in the valence band are considered charge carriers. The number of these charge carriers is dependent on the temperature and the material. As the temperature increases, more electrons have the energy needed to "jump" to the conduction band. (Important: The electrons do not move from a place in the crystal, called the valence band, to another place, called the conduction band. The electrons have the energy associated with the valence band, and acquire enough energy to have the energy associated with the conduction band. An energy change occurs, not a position change.)

Doping: Doping of a semiconductor material, by adding atoms with one more or one less valence electron than the base material, is one method of increasing the number of charge carriers (such as adding Ga, with three valence electrons, or As, with five valence electrons, to Ge or Si which has four valence electrons). Addition of a Group V element, such as As, forms an n-type material, which provides new "donor" energy levels. Addition of a Group III element, such as Ga, forms a p-type material, which provides new "acceptor" energy levels. The energy needed for an electron to move from the valence band to the acceptor level as with Ga (forming a hole), or from the donor level to the conduction band as with As (yielding a conducting electron) is less than the energy needed to make the original "jump" from the valence band to the conduction band of the pure semiconductor material. Thus, for a doped semiconductor material as compared to a pure semiconductor material (at the same temperature), the doped semiconductor would have more electrons in the conduction band (n-type), or more holes in the valence band (p-type). For an n-type material, the carrier of electricity is a negative electron. For a p-type material, the carrier is a positive hole. As the temperature increases, the atoms do vibrate with greater amplitude. However, the increase in number of charge carriers has a greater effect on increasing the material's conductivity than the reduction caused by the

vibrating atoms.

Resistor: When a voltage is applied across a resistor, an electric field is established. This electric field "pushes" the charge carriers through the resistor. This "push" gives the charge carriers a "drift velocity" in the direction from high potential energy to low potential energy. As the voltage increases, the drift velocity increases. Since the amount of current flowing through a resistor is directly proportional to the drift velocity, the current is directly proportional to the voltage, which produces the electric field, which produces the drift velocity. This is the origin of Ohm's Law.

Diode: However, in a diode, the number of charge carriers is dependent on the number of electrons that have enough energy to move up an energy hill and across the p-n junction, producing current flow through the diode. The size of this hill, or energy barrier, is dependent on the amount and type of dopants in the semiconductor material of which the diode is made. As a voltage is applied (in the forward bias), the size of the hill is decreased, so more electrons have the energy needed to cross the p-n junction producing current flow. The number of electrons with the energy needed to move up the hill and across the junction increases exponentially as the voltage increases. Thus, the current increases exponentially as the voltage increases.

Applications:

The behavior of components in a circuit is a very important aspect of circuit design. Diodes are found in many semiconductor circuits. Their non-linear I-V behavior makes them quite useful for a variety of applications. Resistors are often used in series with another circuit component to reduce the voltage across that component or in parallel to reduce the current through a component.

Materials and Supplies:

DC Power Supply

Germanium or Zener Diode

2-1K Ohm Resistors

6 lead wires (including those on the power supply)

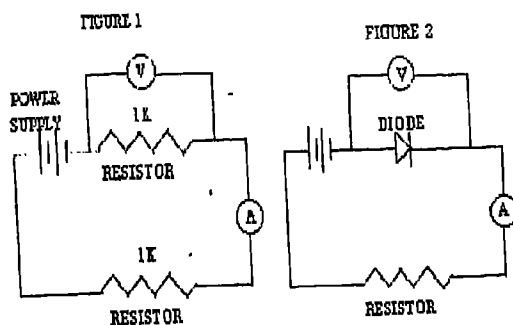
Milliammeter or Galvanometer

Voltmeter

General Safety Guidelines:

- * Always reset the power supply dial to zero, before building or changing the circuit.
- * Keep your hands and the work area dry to avoid shock.
- * Follow safe and correct procedures for operating the power supply.

Experimental Setups:



Procedure:

Circuit set-up:

- Build a circuit as shown in Figure 1. Do not turn on the power supply.
- Check to make sure the lead wires on the power supply are connected to the DC terminals.
- Rotate the voltage and current (if applicable) dial to zero. Rotate the current dial one quarter turn clockwise.

4. Now turn on the power supply.

- Slowly rotate the voltage dial clockwise, and watch the milliammeter and voltmeter dials. If the needle moves to the right, the meters are correctly connected. If the needle moves to the left, reverse the lead wires on that meter.

Resistor (forward):

- Rotate the voltage dial clockwise slowly until the milliammeter needle shows full deflection. Record this milliammeter and voltmeter reading as the maximum, $I_{\max}$ and $V_{\max}$.
- Divide the value of $I_{\max}$ by 5. This is the increment, δI , by which you will increase the current. (You will collect 5 sets of data.)
- Rotate the voltage dial to zero.
- Rotate the voltage dial clockwise slowly, until the milliammeter reads δI .
- Record the values of I and V in the resistor data table.
- Increase the voltage until the milliammeter reads $2\delta I$.
- Record the values of I and V in the data table in rows 1-5.

7/11/2003

Identification of Electronic Components

Semiconductor Contents

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13. Continue to increase the voltage and record I and V , until you reach $I_{\max}$.

14. Rotate the voltage dial to zero.

Resistor (reverse):

15. Reverse the resistor, so the current will flow through it in the opposite direction.

16. Repeat steps 10-16, recording the values of I and V as negative numbers in the resistor data table in rows 6-10.

Diode (forward):

17. Remove the resistor from the circuit and replace it with the diode as shown in Figure 2.

18. Check to make sure the positive end of the diode is connected to the positive terminal of the power supply.

19. Repeat steps 6-14, however, this time divide the $I_{\max}$ by 10, and record the data in the diode data table.

Diode (reverse):

20. Reverse the diode and repeat steps 9-14, using the same values of ΔI as in step 19. Record these values of I and V as negative numbers.

21. Turn off the power supply.

22. Disconnect the lead wires and replace the equipment in their appropriate places.

Data and Analysis:

Resistor Data Table

V (volts)	I (mA)	V/I(ω)

Divide the value of V (volts) by the value of I (amps) to find values of V/I (ω), and complete the data

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9. Which device conducts electricity both directions?
10. Which device conducts electricity only in one direction?
11. Name the 2 types of charge carriers.
12. In a metal, what conducts electricity (carries charge)?
13. In a semiconductor, what carries charge?
14. In a resistor, increased voltage has what effect on the charge carriers?
15. In a diode, what changes to allow more current to flow as the voltage is increased?

Extension:

Plot V (volt) on the x-axis and $\ln I$ (natural log of the values of I in amps, not milliamps) on the y-axis, for the data from the diode section for the experiment (in forward bias). The equation for this relationship is:

$$I = I_0 (\exp^{eV/kT} - 1)$$

where the values of the variables and constants are:

$e = 1$ electron volt/volt

$V =$ volts

$k = 8.62 \times 10^{-5}$ electron volts / K

$T =$ Temperature in K

$I_0 =$ current value when $V = 0$

$I =$ amps

Solve this equation by taking the natural log of both sides.

$$\ln I = \ln I_0 + \ln (\exp^{eV/kT} - 1)$$

substituting the values of e , k , and T in the equation will prove that the value of eV/kT will be about 100V. Therefore, $\exp^{eV/kT}$ will be $\exp^{100V}$ which is much greater than 1, so we can disregard the 1. Now the equation is:

$$\ln I = \ln I_0 + eV/kT$$

The slope of the graph (line) is e/kT . From the graph, find the slope. Set the value of the slope equal to e/kT . Slope $= e/kT$, using the values of k and e , solve for the value of T . Compare this value of T to the room temperature in K.

Teacher Notes:

<http://matse1.mse.uiuc.edu/~tw/sc/d.html>

7/11/2008

*Teacher preparation time is approximately 30 minutes.

*This experiment is designed to be used in the electricity unit of a physics class with students who have already learned how to set up circuits and use test meters.

*For the procedure steps:

1. The teacher should demonstrate the proper procedure for connecting an ammeter and voltmeter in a circuit.
2. The teacher should demonstrate the proper procedure for operating a power supply.
3. If the power supply does have a current dial, the student may have to adjust this dial to allow sufficient current to flow through the circuit, as the voltage is increased.
4. If digital multimeters are used, use voltages from 0-2V as shown in the sample.

Answers to Questions:

1. Use separate graph papers, because the scale of each will be different.
2. This should be a straight line. Make sure the students draw the best line through the data points; they should not "connect the dots".
3. This should be exponential. Have the students use a ruler (straight edge) to approximate the slope of the graph as V increases, by drawing a tangent line at various points on the curve.
4. Have the students draw a large right triangle, representing the $[\Delta]I$ and $[\Delta]V$, the sides of the triangle. The units should be part of the description of the slope. The units may help the students relate the slope to the measurable quantity it represents.
5. If the slope is $5I/V$, its value should be reciprocal of $5V/I$.
6. Resistance.
7. Conductance is the reciprocal of resistance.
8. The values of V/I decreased as V increased.
9. Resistor
10. Diode

11. Electrons and holes.
12. Electrons in the valence band.
13. Electrons that have jumped to the conduction band and the corresponding holes in the valence band.
14. Increased voltage causes a stronger electric field, which pushes the electrons harder in the direction opposite to the field, which increases the drift velocity; so more current flows.
15. As the voltage increases, the size of the hill (energy gap) is decreased, so more electrons (at this temperature) can move up the hill and across the p-n junction.

Data and Analysis:

Sample Resistor Data Table
(forward same as reverse)

V (volts)	I (mA)	V/I ω
0.21	0.21	1000
0.41	0.41	1000
0.61	0.61	1000
0.81	0.81	1000
1.09	1.09	1000
1.20	1.20	1000

Sample Diode Data Table

V (volts)	I (10 ⁻⁶ A)	V/I ω
.14	50	2800
.18	100	1800
.20	150	1300
.22	200	1000
.24	250	960
.26	300	870
.27	350	770
.28	400	700
.29	450	760
.14	0	∞
.18	0	∞
.20	0	∞
.22	0	∞
.24	0	∞

.26	0	∞
.27	0	∞
.28	0	∞
.29	0	∞

*No current in the reverse bias

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Experiment 5

Alternating to Direct

Rectifying Alternating Current

Objective: The objective of this experiment is to illustrate how a diode can be used to rectify alternating current. The student will use a galvanometer to determine the direction of current flow, when an AC or DC voltage is applied to a circuit containing a diode in series with a resistor and a galvanometer.

Review of Scientific Principles:

For current to flow through a diode, the electrons must move up an energy hill and across the p-n junction. As a voltage is applied in the forward bias, the size of the hill is decreased, so more electrons have the energy needed to move up the hill and across the junction (making current flow). However, if the voltage is applied in reverse bias, the hill is made bigger, so very few electrons have the energy needed to move up the hill. Thus, a diode generally conducts current in only one direction.

Applications:

When you plug an electrical device or appliance into an ordinary wall receptacle at your house, you are using 110 volt AC (alternating current). The electricity was probably produced at a power plant by using a fuel to produce steam, to turn a turbine, to turn an electric generator. The generator spins at 3600 RPM, which is 60 revolutions per second (60 Hz). Many household items are designed to operate on AC, however, some items such as battery chargers, electric trains, and other toys are designed to operate on DC. Diodes are used as rectifiers, to convert AC to DC.

Time: 20-30 minutes

Materials and Supplies:

AC-DC Power Supply

Lead wires

Galvanometer

1-1/2" wire resistor

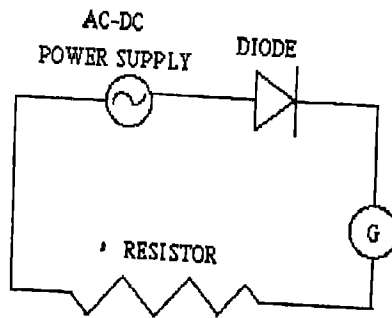
Diode (germanium, zener, or LED)

General Safety Guidelines:

*Make sure the power supply dials are set at zero when building or adjusting a circuit.

*Keep your hands and the work area dry to prevent shock.

Experimental Setup:

**Procedure:**

1. Build the circuit shown in the Experimental setup, and be sure to connect the positive terminal of the diode to the positive terminal of the power supply.
2. Use the DC terminals of the power supply.
3. Make sure the voltage dial on the power supply is set at zero.
4. Turn on the power supply.
5. Slowly rotate the voltage dial clockwise, and watch the galvanometer needle. Do not bury the needle.
6. Record the direction of needle movement.
7. Rotate the voltage back to zero.
8. Reverse the direction of the diode and repeat steps 5-7. Do not increase voltage past 2V.
9. Disconnect the lead wires from the DC terminals, and connect them to the AC terminal on the power supply.
10. Repeat steps 5-8.

Data and Analysis:

Type of Current	Direction of Current	Direction of Galvanometer

Questions:

1. Will the current flow through a diode both directions?
2. How should a diode be connected in a circuit so current will flow through it?

3. How does a diode effect AC current?
4. Draw a graph of current (vertical axis) vs. time (horizontal axis) for AC current.
5. Considering how a diode affects AC current, draw what you think a graph of current vs. time should look like for the circuit you built using AC current and a diode.
6. Draw a graph of current vs. time for a DC current, like that produced by a battery.
7. How does the current produced by the AC - diode circuit differ from DC current produced by a battery?
8. How does increasing voltage effect the ability of a diode to allow current to flow?
9. Why does a diode with a voltage applied in reverse bias restrict current flow?
10. Will a diode change alternating current to direct current (like the current produced by a battery)?

Extension:

1. Use a hand generator, a resistor, and a galvanometer to show needle movement with alternating current. Use a $1K\Omega$ resistor, to protect the galvanometer.
2. Use a frequency generator diode and an oscilloscope to show the wave form of alternating current and rectified alternating current.
3. Obtain the schematic of a full wave rectifier, which uses diodes and capacitors to produce approximately steady direct current. Consult an electronics handbook for the details.

Teacher Notes:

*Teacher preparation time is approximately 30 minutes.

*If the diode is improperly connected, the results will be reversed.

*The teacher should demonstrate proper operation of a power supply.

*If a digital multimeter is used, use the milli-amp or micro-amp scale. The student should record the sign (+, -) of the current value.

Answers to Questions:

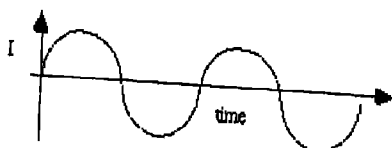
1. No

Rectifying Alternating Current

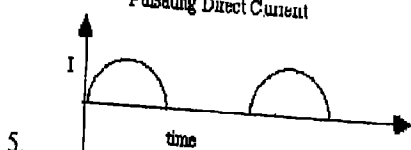
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2. Positive terminal of the diode to the positive terminal of the power supply.
3. A diode will rectify AC current, which means the produced current will be a pulsating direct current. It will pulsate at the same frequency as the frequency of the alternating current.
4. The graph will be a sine wave.

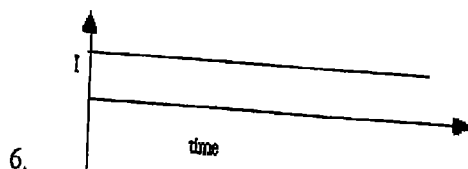
Alternating Current



Pulsating Direct Current



5.



6.

7. The current produced by a battery is steady, while that produced by the action of a diode on AC current is pulsating. A 5 amp DC current is more powerful than a rectified AC current varying from 0-5-0 amps.
8. Increasing the voltage decreases the size of the energy hill that the electrons have to move up, so more electrons can move up the hill and across the p-n junction, allowing more current to flow.
9. A reverse voltage increases the size of the hill, so few electrons have the energy needed to move up the hill. Most meters will show no current flowing in the reverse direction.
10. No, only with the addition of a capacitor will the current begin to level off.

Sample Data Table:

Type of Current	Direction of Current	Direction of Galvanometer
-----------------	----------------------	---------------------------

DC	+ to -	right
DC	- to +	none
AC	+ to -	right
AC	- to +	left

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Experiment 6

Working with LED's

Estimating Semiconductor Band Gap using LED's

Objective: Observe visible light-emitting diodes (LED's) in simple electrical circuits, and relate the composition of semiconductor materials with their behaviors. Estimate the band gap of a semiconductor material.

Review of Scientific Principles:

Colored light can be produced in a number of ways. On the one hand, ordinary incandescent light bulbs may be used with filters that select out a portion of the complete color spectrum that is emitted from the glowing wire filament. On the other hand, the familiar orange-red glow of neon lights is generated by electrically ionizing very small amounts of gases inside sealed glass tubes. LED's contain neither a wire filament nor any gases. The light emitting portion of a solid state diode is quite small so you will need a magnifying glass to see it clearly. Even though the diode may be enclosed in a colored plastic lens, the lens is not the cause for the color of the light observed.

In LED's, electrical energy is converted into light energy. The voltage required to switch on the LED is proportional to the energy of the light emitted from that LED. Also by comparing the color of the light with a chart of the visible light spectrum, it is possible to assign a wavelength to the color of each LED. Using this wavelength, a simple calculation can be made to approximate the energy of the electron transition taking place at the junction in the diode. The colored light (made up of photons) is being produced by electrons that are relaxing across the energy gap in the semiconductor material. The reverse process may also be observed in which light shining on a diode can be converted into electrical energy.

Applications:

LED's are very common and are frequently used as indicator lamps. When the light goes on, electricity is flowing. Whether it is a compact disc player, electric guitar amplifier, computer, monitor, or video game module, we always look for the little colored light to let us know it is working. As common as they are, however, most people have no idea how LED's produce their bright, colored light; they simply expect it to happen.

Time: One hour. (More time is required if students will be assembling the circuits themselves).

Materials and Supplies.

Each student group will need:

variable power supply (at least 0-6 VDC) with leads

one panel containing several different visible LED's (see note 1)

digital multimeter (DMM) and test leads with small alligator clips

magnifying lens

9V battery and snap connector,

<http://matse1.mse.uiuc.edu/~tw/sc/f.html>

470 Ω resistor

LED socket (see note 2)

small, bright flashlight

General Safety Guidelines:

*Do not stare long at any of the brightly lit LED's.

*Some of the wires may have sharp edges.

*Do not grasp any bare wires or connections with your hands.

*Be sure the power supply is set for 0-6 V (DC). Turn it off when not in use.

Procedure:

1. Obtain a panel containing several different visible LED's.
 2. Connect the power supply 0-6V DC to the panel leads.
 3. Connect the DMM across the circuit, and set it for DC.
 4. With the power supply at its lowest setting, turn it on.
 5. Slowly dial up the voltage until an effect is noticed at one of the LED's.
 6. Continue to slowly dial up voltage until you have observed all the LED's (do not let the voltage reading on your DMM exceed 2.5V).
 7. Now slowly dial the voltage back down, and observe the LED's.
 8. Repeat steps 5-7. Record the voltage at which you observe each LED to go on and off.
 9. With all LED's on and shining brightly, compare their colors with a chart of the visible light spectrum. Or view the lighted LED's with a calibrated spectroscope. Record the wavelength in nanometers of the color that matches each LED.
 10. Turn off the power supply, and disconnect only its positive lead from the circuit. Leave the DMM on and its leads in place across the LED circuit.
 11. With the room darkened, shine a small, bright flashlight on each of the LED's in the panel. Record the maximum voltage that you read from the DMM for each LED.
 12. Obtain a 9V battery and snap connector with appropriate resistor and socket. Insert a green light LED in the socket with the long leg on the red side. Shine it directly over
- <http://matse1.mse.uiuc.edu/~tw/sc/f.html>

- and against each of the LED's in the panel. Record the maximum voltage for each that you read from the DMM.
13. Repeat step 12 replacing the green LED with a red LED. Record the voltage readings.
14. Test what happens when an LED is placed in the socket backwards.
15. Using a magnifying glass, make two scaled drawings of an LED--one from the top and one from the side. Indicate on your drawings where the light is produced.

Video Clip Demo

Data and Analysis:

LED Color	Turn-on	Wavelength of light Emitted	Energy of Light Emitted	Band Gap of Material	Composition of Material

Questions:

1. In what order do the LED's light when the voltage is increased slowly from zero?
2. Place the LED's in order according to increasing wavelengths.
3. What is the relationship between the lists in questions one and two?
4. From your observations, what kind of mathematical relationship exists between the numerical values for electrical energy (volts) and the wavelength of the colored light emitted?
5. What effect does the white light source have on the LED's? Why?
6. Which color of LED caused a voltage reading in every LED on the panel?
7. Which color of LED caused a voltage reading in only one LED on the panel?
8. Explain your answers to questions six and seven by discussing the relationship between energy and color of light.
9. In which LED is the diode composed of a material with the largest band gap?
10. Calculate the band gap for the material in each diode in units of electron volts (eV) by

using the equation $E = 1240 / \lambda$. Where λ is the wavelength of light in nanometers (10^{-9} meters).

11. Compare the values calculated with a list of semiconductors and their band gaps.

Which materials do you believe are present in the LED's that you used?

Teacher Notes:

*Teacher preparation time for this lab is approximately one hour.

*The panels can be constructed in a number of ways, but one that seems to work uses ordinary 1/4 inch pegboard. Cut a square that has at least five rows and columns of holes (more or less depending on the number of LED's). Make a red line down one side of a row. Pop an LED of each color (use colorless lens LED's to ensure that students realize the colored light is not due to the plastic case) into a mounting clip. Then press these through the holes in the pegboard with the longer leg of the LED on the side of the red line. The legs may now be trimmed to any convenient length, but leave enough for solder connections. Now solder a noninsulated copper wire to each of the "red" legs and one to each of the "black" legs leaving a least 2 cm for connections to the power supply. Then solder a 470 Ω resistor to the wire on the red side.

*Solder a 470 Ω resistor to the red lead of the 9V battery snap connector. Then solder an LED socket to the other end of the resistor and the black lead from the snap connector.

*Sources for materials are: Radio Shack, Mouser Electronics (800)346-6873, Cal-West Electronics (800)892-8000 (blue LED's can be purchased for \$2.50 each)

*Rohm super-bright LED's from the Mouser catalog are a good choice at \$0.15/lamp. These are the catalog numbers:

red 592-SLH34-VT3

orange 592-SLH34-DT3

yellow 592-SLH34-YT3

green 592-SLH34-MT3

*See Ken Werner's article *Higher visibility for LED's* in July 1994 IEEE Spectrum magazine for a great summary of LED technology.

<http://matse1.mse.uiuc.edu/~tw/sc/f.html>

Answers to Questions:

1. red, orange, yellow, green, blue
2. blue, green, yellow, orange, red
3. opposite order
4. from observation, it is opposite or inverse
5. a voltage is produced in the circuit when it is shone on each LED because white light is a combination of all colors of visible light
6. green (or blue)
7. red
8. green (blue) light is of the highest energy, and it is able to promote electrons across the band gap in all the LED's, but low energy red light can only affect electrons in the red LED with the small band gap.
9. green (blue)
10. green (blue)
11. The published values of wavelengths for the LED's are red at ~650 nm, orange ~610 nm, yellow ~585 nm, green ~565 nm, blue ~470 nm observed colors may vary but should fall between about 460 - 700 nm

Use the following information:

SiC	2.64 eV	blue
GaP	2.19 eV	green
GaP.85As.15	2.11 eV	yellow
GaP.65As.35	2.03 eV	orange
GaP.4As.6	1.91 eV	red

Next Topic: Module Quiz

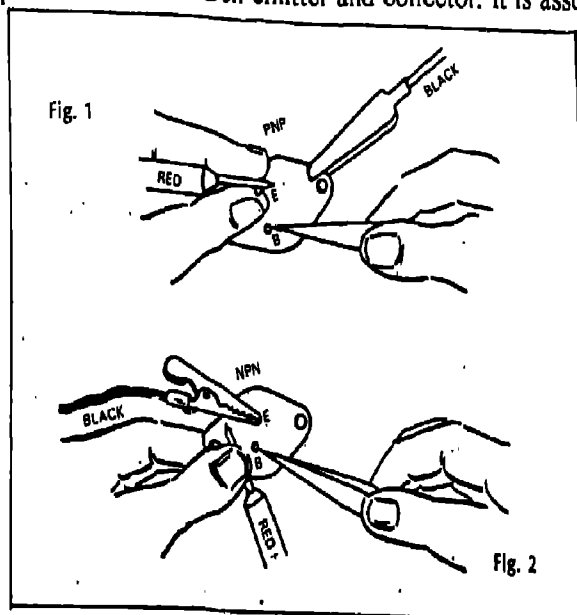
Semiconductor Contents

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1. Testing a Transistor Without a Transistor Tester.

It is perhaps easy to tell all types of transistors with a transistor tester. But it is not so easy to determine by means of common gadget how much capacity of amplifying a transistor has lost or retained after use.

In the normal ohmmeter test, resistance is checked across each pair of electrodes of a transistor. If resistance between emitter and base, and between base and collector are very low compared to that between emitter and collector. It is assumed that the transistor is alright.



But the resistance between two electrodes varies from transistor to transistor, even if they are of the same type. This naturally creates confusion, especially in case of power transistors because resistance between emitter and collector of such transistors is very small. As such, it is very hard to arrive at a conclusion.

In spite of these difficulties a transistor can be successfully tested with an ohmmeter (or multimeter) as described below.

Keep the selector of the ohmmeter at $\times 1k$ position. If the transistor to be tested is pnp type, the negative probe (black) should be connected to the collector of the transistor with the help of a crocodile clip. Then the emitter may be touched with the positive probe (red) of the meter, pressing it with your left thumb. Now hold a small stainless steel forcep in the right hand and touch the base of the transistor with it several times (as in illustration no. 1) keeping a watch over the ohmmeter to see how far its needle deflects toward the zero reading. If the swing of the needle is sufficient. It indicates that the transistor's amplifying capacity is intact; a small swing indicates less amplifying capacity. If there is no deflection of the needle, it means that the transistor has become out of order. If however the needle shows zero reading, it means that the transistor leaks very badly.

While testing npn type of transistors, just reverse the above procedure (as shown in illustration no. 2). That is, connect the positive probe of the ohmmeter to the collector of the transistor with the help of a crocodile clip, press the negative probe upon the emitter with the left thumb and touch the base of the transistor with a forcep in the right hand several times to determine the amplifying capacity of the transistor, watching the deflection of the meter needle.

I suppose every technician has at least one multimeter and with a bit of practice he can easily test a transistor through this method. With some imagination the method can also be adapted to determine the type of transistors and to locate their terminals, i.e. collector, emitter and base of a transistor.

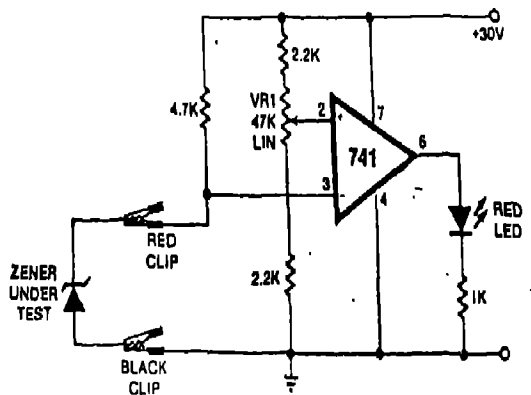
Note that the red probe of an ohmmeter actually holds a negative potential and a black probe a positive potential. Even though the red and black probes are connected to the positive and the negative polarities respectively to measure the DC voltage.

Caution: A power transistor should always be allowed to cool before testing with an ohmmeter.

By Dwijendra Nath Roy

2. Zener Tester

This tester helps to check the voltages of zener diodes. It is very inexpensive and handy to find the voltages of small glass zener, whose marking gets rubbed – off very easily. The 741 op-amp has been used in different mode.



The 47 k linear potentiometer's dial is calibrated in terms of voltages between 0 and 27 V, either by using various known zeners in the range, or by applying a known voltage at pin 3 of IC 741. The position of the potentiometer where the LED gets turned off, gives the breakdown voltage of the zener.

The power supply voltage can be between 9V and 30 V. But, zener to be tested, and should not be changed once the dial is calibrated.

You can also check the polarity of zener. The cathode side should be connected to the red clip (i.e. pin 3 of IC 741). If you connect the zener the other way round, then it will just behave as a diode, and the Led will remain off at all positions of the potentiometer.

In case of a zener that is shorted from inside, the LED will remain off with zener connected either way to the clip. In case of a zener that is open – circuit from inside, the LED keeps glowing at all position, with zener connected either way to the clip.

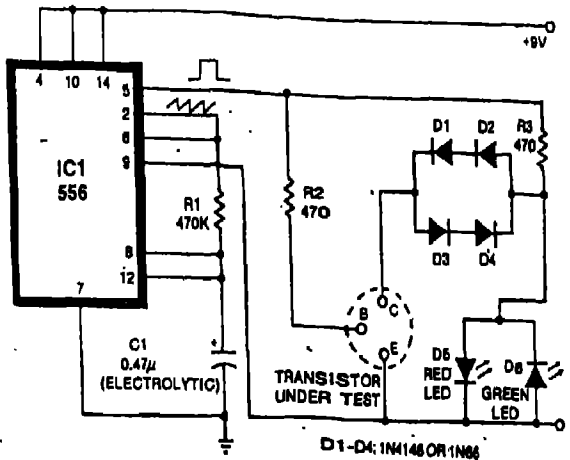
You may even differentiate between a diode and zener by their behavior on this versatile tester.

3. In – Circuit Transistor Tester.

Here is a circuit that can indicate the condition of a transistor by using two LEDs. A good npn transistor conducts during the positive half cycle (pulses are generated by 556 dual timer) and D5 is off while D6 flashes. With a good pnp transistor D6 is off and D5 flashes.

Both LEDs flash if the transistor is open and will be off if it is shorted.

The tester checks the transistor even if in – circuit resistance across the transistor is as low as 50 ohms; below this the glow becomes dim. Diodes in the circuit ensure that only low saturation voltage of a good transistor turns the Led off.



Condition of LEDs is shown below:

Condition of LEDs is shown below:

S. No.	Transistor	LED D5	LED D6
1.	Good npn	Off	Flashing
2.	Good pnp	Flashing	Off
3.	Open Circuit npn or pnp	Flashing	Flashing
4.	Short Circuit npn or pnp	Off	Off

By S.K. Nagar

4. Simple Transistor Tester.

Here is a simple and inexpensive transistor tester which is very useful for the radio technician and hobbyist. You can quickly make Go/No Go (good or bad) checks on both npn and pnp transistor with it. The tester also enables a technician to identify the transistor type – whether it is an npn or pnp transistor.

The circuit of the transistor tester is shown in the figure. The transistor under test is shown connected with dotted lines. The circuit is basically an audio frequency oscillator of the HARTLEY type, which produces a whistling sound from the loudspeaker. The capacitor C2, connected between the upper end of the primary of the output transformer and the base of the transistor provides the necessary positive feedback. Due to the positive feedback, the circuit oscillates producing an audio tone from the loudspeaker. An open (not conducting) or a

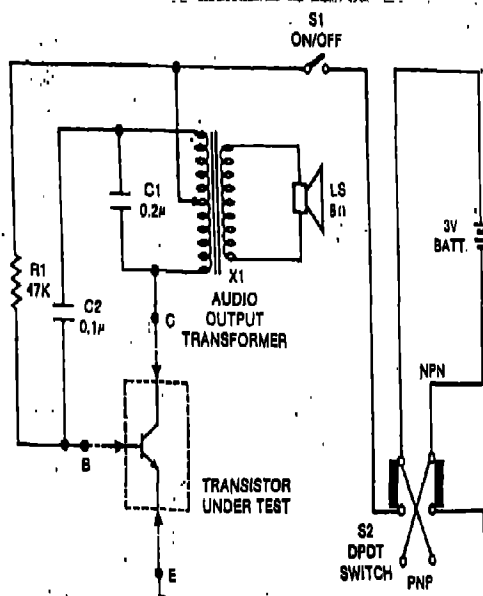
shorted transistor does not produce the oscillatory tone from the loud speaker. Indicating that the transistor is defective. This is the principle used in this tester.

Resistor R1 provides the necessary base bias to the transistor and the capacitor C1 controls the frequency of oscillation.

Three pieces of PVC flex wires of about 25 cms in length are connected to terminals marked C, B and E of the tester, and brought out through separate holes made at top of the box housing the tester. Three small crocodile clips are soldered to the other ends of the wires. Red wire for collector, yellow for base and black for emitter are used, for easy identification. For reversing the polarity of the battery, a DPDT slide switch (S2) is used. The connection to the DPDT slide switch is also shown in the figure to identify whether the transistor is pnp or npn.

To test a transistor, for example AC128, put the slide switch S2 into PNP position and the on / off switch (S1) to ON position. Carefully connect the three crocodile clips to the relevant leads of the transistor under test. If the transistor under test is good it will produce a whistling sound from the loudspeaker of the tester. An open (not conducting) transistor will not produce any sound. A shorted transistor will produce a loud 'click' when connected and no whistling sound. Disconnect such a transistor immediately to prevent the battery from discharging.

The tester works well with almost all such transistors as AF115, BF194, BC148, AC128, AD149 and 2N3055. The tester current never exceeds 3.5 mA with a good transistor. Hence any transistor may safely be tested with this devi



Transformer X1 is the push – pull output transformer used in germanium radio. A good quality 4 or 8 ohm, 6.2 cm to 7.5 cm loudspeaker will produce sufficient sound. C1 and C2 are disc type ceramic capacitors. R1 is of 0.25 watt rating. Two penlight cells fitted in PVC holder are used to power the tester. As the test current is very low, the battery may last for more than a year.

The tester may be assembled on a small piece of veroboard and fitted into a small wooden or plastic box.

By: P. VENKATARATNAM

5. LED Semiconductor Tester

Fig 1 shows an LED circuit that can test diodes and transistors either in or out of circuit. It can also be used for determining the type of a transistor, i.e. whether pnp or npn. The circuit comprises a 3 V transformer connected in series with a parallel combination of two LEDs and two resistors. A pair of shells of ball-point pens can be used for making probes with an LED mounted on each of them. If the two probe tips are shorted both the LEDs will glow.

To test a diode, touch the probe tips across the diode to be tested.(Fig2). If the diode is good, LED in the probe on the anode side will glow and the other will not. If the diode is short, both the LEDs will glow. If the diode is open, none of the LEDs will glow.

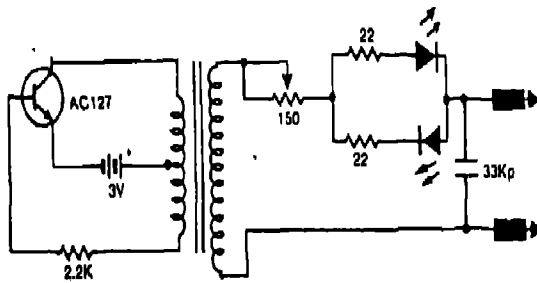


Fig. 1

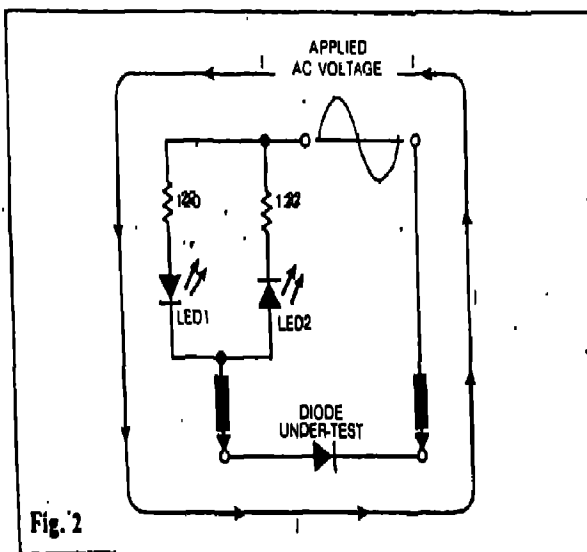


Fig. 2

A transistor can be considered as two diodes connected back to back, for checking purpose. The above mentioned method can therefore be used for checking transistor junctions also. To find the class of transistor, apply one probe to the base and the other either to the collector or emitter. If the base LED glows, the transistor is npn, but if the other LED glows, it is an pnp transistor.

The LED currents are low and will not damage the devices under test.

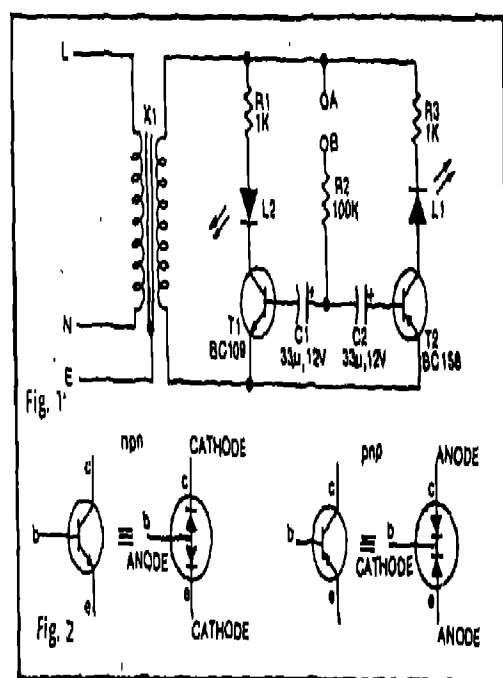
By M.A. PREM KUMAR

6. Diode Tester

Using this easy-to-operate tester, low current diodes and transistors can be tested. The maximum current that follows through the diode under test is 100 microamperes.

X1 is any mains step-down transformer capable of providing 50 mA (or more) current at 9 volts.

Connect the diode to be tested to terminals A and B. Both the LEDs will light up if the diode is shorted inside, and none if it is open. In both the cases, the diode is useless. The diode terminal connected to A is the anode if L2 lights up and cathode if L1 lights up.



Representation of transistors (npn and pnp) in terms of diodes is shown in Fig. 2. It will be seen that transistors too can be tested by testing their diode junctions. This tester could be very useful in testing surplus diodes and transistors.

By J. SREEKUMAR

Source:- EFY Circuit ideas

Point to remember:-

Data Communication:-

1. Data communication is the transmission and reception of binary data between computers and other digital equipment
2. The earliest form of electronic communications, the telegraph, was a type of data communications.
3. Turning a carrier off and on in a code of dots and dashes is a kind of data communications known as continuous wave (CW).
4. Teletype is a form of telegraph that uses the 5-bit Baudot code to transmit between typewriter like units.
5. The most widely used binary data communication code is the 7-bit American Standard Code for information Interchange (ASCII)
6. Another popular code is the 8-bit Extended Binary Coded Decimal Interchange Code (EBCDIC) used mainly in IBM system.
7. The two main methods of data transmission are serial and parallel. In serial transmission each unit is transmitted sequentially. In parallel transmission, all bits are transmitted simultaneously.
8. Serial transfers are slower than parallel transfers but require only a single line or channel. Parallel transfers require multiple channels of lines called a bus.
9. The speed of data transmission is designated in terms of bits per second (bits/s) or baud.
10. Baud rate is the number of symbol changes per second. A symbol is an amplitude frequency, or phase change.
11. The channel or bit rate capacity of a channel is directly proportional to the channel bandwidth and the time of transmission.
12. The channel capacity or binary signal transmission rate in bits per second is equal to twice the channel bandwidth B when no noise is present ($C=2B$)
13. When multiple levels or symbols are used to encode the data, the channel capacity C is greater for a given bandwidth B , or $C = 2 \log_2 N$ where N is the number of symbols used.
14. The channel capacity C in bits per second is proportional to the channel bandwidth B and power S/N ratio, or $C = B \log_2(1+S/N)$
15. The bit rate is higher than the baud symbol rate if multiple-level symbol encoding is used.

16. The two methods of data transmission are asynchronous and synchronous. In asynchronous transmission, data is sent one character at a time with start and stop bits. In synchronous transmission, data is sent as a continuous block of multiple characters framed with synchronization characters.
17. Synchronous transmission is faster than asynchronous transmission
18. In data communication, a binary 1 is referred to as a mark and binary 0 as a space.
19. Signal, whether voice, video, or binary, transmitted directly over a cable are known as baseband signals.
20. Voice and video signal are analog but may be converted to digital for data communications transmission.
21. Signals that involve a modulated carrier are called broadband signals.
22. Communications of binary data signals over the telephone network, which is designed for analog signals, is made possible by using a modem.
23. A modem is a modulator – demodulator unit that converts digital signal to analog and vice versa.
24. The most commonly used modulation techniques in modems are frequency-shift keying (FSK), phase shift keying (PSK), and quadrature amplitude modulation (QAM).
25. Frequency – shift keying uses two frequencies for binary 0 and 1 (1070 and 1270 Hz or 2025 and 2225KHz. It operates at speed of 300 baud or less.
26. Modems capable of transmitting at standard higher rates of 1200, 2400, 4800 and 9600 bits's use PSK and /or QAM.
27. Binary PSK(BPSK) uses a carrier of 1600 or 1700 Hz where phase of 0° represents a binary 0 and a 180° phase shift represents a binary 1, or vice versa.
28. Binary PSK is generated by a carrier and data.
29. Binary PSK is demodulated by balanced modulator.
30. The properly demodulate BPSK, the carrier at the demodulator must have exactly the same phase as the transmitting carrier.
31. A special carrier recovery circuit in the receiver produces the correct phase carrier from the BPSK signal.

32. Different PSK eliminates the need for a special reference phase carrier by using a special coding technique where the phase of each bit is referred to the previous bit.
33. Quadrature PSK uses four equally spaced phase shifts of the carrier to represent two bits(dbits) . For example, 00 = 45^0 , 01 = 135^0 , 11 = 225^0 , 10 = 315^0
34. In 8 – PSK, 3 bits are coded per phase change. In 16 –PSK, 4 bit are coded per phase change. Thus the bit rate is 3 Or 4 times the symbol rate change or baud rate.
35. Quadrature amplitude modulation uses a combination of QPSK and two – level AM to code 3 bit combinations is represented by unique phase and amplitude signal.
36. A protocol is a rule or procedure that define how data is sent and receives.
37. Protocol include “ handshaking” signals between the transmitter and receiver that include the status of each.
38. The Xmodem protocol is widely used in personal computers.
39. In Synchronous communication, a variety of special characters are sent before and after the block of data to ensure that the data is correctly received.
40. Bit errors that occur during transmission are caused primarily by noise.
41. The ratio of the number of bit errors that occur for a given number of bits transmitted is known as bit error rate (BER).
42. Error detection and correction schemes have been devised to reduce bit errors and increase data accuracy.
43. One of the most widely used error detection scheme adds a parity bit to each character transmitted, making total number of binary 1s transmitted odd or even. If a bit error occurs,, the parity bit derived at the receiver will differ from the one transmitted.
44. Parity generator circuits are made up of multiple levels of exclusive OR (XOR) gates.
45. Another name for parity is vertical redundancy check (VRC).
46. The longitudinal redundancy check (LRC) is another way to test for errors. Corresponding bits in adjacent data words are exclusive – Ored to generate a block check character (BCC) that is appended to the transmitted block.
47. If the VRC and LRC provide a coordinate system that will identify the exact location of a bit error so that it may be corrected.

48. A widely used error detection scheme is cyclical redundancy check (CRC) where the data block is divided by a constant to produce a quotient and remainder. The remainder is the CRC character, which is attached to the CRC computed at the receiver.
49. A network is any interconnection of two or more stations that can communicate with one another.
50. An example of a wide area network (WAN) is the telephone system. An example of a metropolitan area network (MAN) is a cable TV system.
51. A local area network (LAN) is an interconnection of stations in a small area over short distances such as in an office building, or on a college campus.
52. Local area networks were conceived to allow PC users to share expensive peripherals such as hard disks and printers but are now used to general communication and the sharing of software and data.
53. The most common physical configuration or topologies of LAN are star, ring, and bus.
54. The bus is the fastest. The ring is the least expensive but is disabled if one station fails.
55. The star configuration is commonly used to connect many terminals and PCs to a larger mainframe or minicomputer.
56. The three most commonly used transmission media in networks are twisted pair, coax, and fiber optic cable.
57. Twisted pair is inexpensive and easy to work with and widely used for short distance, low speed LANs. It is not shielded, so it is susceptible to noise.
58. Coax is the most widely used medium because of its high speed capability and its shielding against noise.
59. Fiber optics cable is growing in usage as its price declines. It has the highest speed capability of any medium.
60. Local area networks use both baseman and broadband refers to transmitting the information signal directly on the medium.
61. Broadband refers to using modulation techniques to transmit the data on carriers that can be assigned specific channels over a wide frequency range on a common medium.
62. Broadband systems require the use of modems at each node.

Fiber Optics:-

Communication Concepts to be remember

1. The information carrying of a cable or radio channel is directly proportional to its bandwidth.
2. The RE spectrum is heavily used and occupied. Only in the microwave region is there room for expansion.
3. Light is an electromagnetic signal like a radio wave but is much higher in frequency. It can be used as a carrier for information signals.
4. Because of the very high frequency of light compared to typical information signals, tremendous bandwidth is easily available.
5. Light waves carrying data signals can be transmitted in free space but are greatly attenuated by atmospheric effects and require pinpoint alignment.
6. Most light wave communication is by way of a glass or plastic fiber cable that acts as a "light pipe" to carry light modulated by information signals.
7. The main components of a light wave communications system are an A/D converter, a light source transmitter, a fiber optic cable, a photo or light detector with amplifier and shaper, and a D/A converter.
8. Because of the great attenuation of light in fiber optic cable, repeater units are used to amplify the regenerate the signals over long distance.
9. The primary application of fiber optic communication is in long distance telephone systems.
10. The primary advantages of fiber optic cables over conventional cables and radio are wider bandwidth, lower loss, light weight, small size, strength, security, interference immunity and safety.
11. The main advantage of fiber optic cable is that its small size and brittleness make it more difficult to work with.
12. Light waves, like radio waves, are a kind of electromagnetic radiation.
13. Light waves occur at very high frequencies in the rang of $3 * 10^{11}$ to $3 * 10^{16}$ Hz.
14. Wavelength rather than frequency is used to express the place of light in the spectrum.
15. The wavelength of light is expressed in terms of nanometers ($1\text{nm} = 10^9 \text{ m}$) or micrometers of ($1 \mu\text{m} = 10^6 \text{ m}$). Micrometers are also called microns.

16. The visible light spectrum is from 700 nm (red) to 400 nm (violet).
17. The optical spectrum is made up for visible light, infrared at lower frequencies and ultra violet at higher frequencies.
18. Infrared rays cannot be seen, but they act like light waves and can be manipulated in similar ways as with a lens or mirrors.
19. Light waves, like microwaves, travel in a straight line.
20. The angle at which light strikes a surface is called the angle of incidence. The angle at which light is reflected from a surface is called the angle of reflection. The angle of incidence is equal to the angle of reflection.
21. When a light ray passes from one medium to another, it is bent. This is called refraction.
22. The amount of refraction is called the index of refraction n and is the ratio of the speed of light in air to the speed of light in another medium, such as water, glass, or plastic ($n = 1$ in air, $n = 1.3$ in water, $n = 1.5$ in glass).
23. The angle of the incident light ray determines whether the ray will be reflected or refracted.
24. The critical angle of incidence is made greater than the critical angle, reflection occurs instead of refraction.
25. If the angle of incidence is made greater than the critical angle, reflection occurs instead of refraction.
26. Light entering a fiber optic cable has an angle of incidence such that light is reflected or bounced off boundary between the fiber and external media. This is called total internal reflection.
27. Fiber optic cables are made from glass and plastic. Glass has the lowest loss but is brittle. Plastic is cheaper and more flexible, but has high attenuation.
28. A popular fiber optic cable with a glass core and plastic cladding is called plastic clad silica (PCS).
29. The step index fiber has a sharp difference in the index of refraction and provides an interface with controlled index of refraction.
30. step index means there is a sharp difference in the index of refraction between the core and cladding.
31. Graded index means that the index of refraction of the core varies over its cross section, highest in the center and lowest at the edges.
32. A single mode cable is very small in diameter and essentially provides only a single path for light.

33. Multiple cores are large and provide multiple paths for the light.
34. Multiple light paths through a step index core cause a light pulse to stretched and attenuated. This is called modal dispersion, and it limits the upper pulse repetition rate and thus the information bandwidth.
35. Multiple light paths in a graded index core are controlled so that they converge at multiple points along the cable. Modal dispersion does occur, but it is not as serve as that caused by step index core.
36. Modal dispersion does not occur in single mode core.
37. The three most widely used types of fiber optic cable are multimode step – index, single mode step index, and multimode graded index.
38. The primary specification of fiber optic cable is attenuation, which is usually expressed as the loss in decibels per kilometer.
39. Light loss in a fiber optic cable is caused by absorption, scattering and dispersion.
40. Cable attenuation is directly proportional to its length.
41. Cable losses range from 1 db / km in glass single mode step index cable to 100 db / kb for plastic multimode step – index cable.
42. Fiber optic cable can be spliced by gluing.
43. Special connectors are used to connect cables tone another and to the equipment.
44. Fiber optic systems use light emitting diodes (LEDs) and semiconductor lasers as the main light sources.
45. Light emitting diodes are used in short distance, low speed systems, Injection laser diodes (ILDs) are used in long distance, high speed systems.
46. Most LEDs and ILDs emit light in the invisible near infrared range (0.82 to 1.35 μm).
47. A popular operating frequency is 1.3 μm because fiber optic cable has an attenuation null at this wavelength.
48. Laser diodes emit monochromatic or single frequency light. The light waves are coherent, so they reinforce one another to create an intense and finely focused beam.
49. Intense laser light is produced by an ILD because reflecting surface in the structure from a cavity resonator for the light waves.

- 50. The most commonly used light sensor is a photodiode.
- 51. A photodiode is an PN junction that is reverse biased and exposed to light. Light increases the leakage current across the junction. This current is converted into a voltage pulse.
- 52. PIN junction diodes are faster and more sensitive than conventional photodiodes.
- 53. The fastest and most sensitive light detector is avalanche photodiode (APD).
- 54. The APD operates with a high reverse bias so that when light is applied, breakdown occurs and produces a fast, high current pulse.
- 55. The receiver portion of a fiber optic system is made up of a photodiode, amplifier, and shaper.
- 56. Fiber optic systems are rated by speed and product of the bit rate and the distance.
- 57. A measure of the quality of a fiber optic system is the maximum distance between repeaters

Section A

Activities to be performed

1. To study collision of two balls in two dimensions.
2. To measure the resistance and impedance of an inductor with or without iron core.
3. To measure resistance, voltage (AC / DC), current (AC) and check continuity of a given circuit using multimeter.
4. To assemble a household circuit comprising three bulbs, three (on / off) switches, a fuse and a power source.
5. To assemble the components of a given electrical circuit.
6. To assemble given resistors in a suitable combination to obtain a desired resistance and verify its value with a multimeter.
7. To find current by measuring voltage across a given resistor.
8. To draw the diagram of a given open circuit comprising at least a battery, resistor / rheostat, key, ammeter and voltmeter. Mark the components that are not connected in proper order and correct the circuit and also the circuit diagram.

Section B

Activities to be performed.

1. To study effect of intensity of light (by varying distance of the source) on the LDR
2. To identify a diode, an LED, a transistor, and IC, a resistor and capacitor from mixed collection of such items.
3. Using of multimeter to
 - a. Identify base of transistor.

- b. Distinguish between npn and pnp type transistor.
 - c. Identify terminal of an IC
 - d. See the unidirectional flow of current in case of a diode and an LED.
 - e. Check whether a given electronic component (e.g. diode, transistor or IC) is in working order.
-
- 4. To observe polarization of light using two polaroids or calcite crystals.
 - 5. To observe diffraction of light due to a thin slit between sharp edges or razor blades.
 - 6. To observe diffraction phenomena from a piece of nylon or China Silk piece and night lamp.
 - 7. Teaching some concepts using Toys available in the local market e.g. magic wheel.
 - 8. To identify the given resistor's wattage and value from relative size of the resistor and colour code disk.
 - 9. To observe the diffraction and interference pattern on a blank Compact disk and CD loaded with the data.
 - 10. To observe the interference & diffraction pattern due to a distant bulb through an Umbrella in a dark and raining season.
 - 11. To study the double refraction and polarization phenomena through Calcite crystal.

PAC 15.21

Training programme for Teaching Hard spots in Higher Secondary physics for Teachers of Jammu and Kashmir and Haryana
(3rd to 7th NOV, 2003)

● Time Table ●

Day	Date	9:30am – 11:00am	11:00am – 11:30am	11:30am – 01:00pm	01:00 pm – 02:00 pm	2:00pm – 3:30pm	3:30pm – 4:00pm	4:00pm – 5:15pm
Monday	03-11-03	Registration Introduction objectives SKP	11:00am – 11:30am	Theory Kinematics (ABS)	01:00 pm – 02:00 pm	Physics Practical (SKP + V Arya)	3:30pm – 4:00pm	Physics Practical (SKP + KCS)
Tuesday	04-11-03	Theory Semiconductors (SKP)	11:00am – 11:30am	Theory Nuclear Physics (HCJ)	01:00 pm – 02:00 pm	Physics Practical (SKP + V Arya)	3:30pm – 4:00pm	Computer Lab (SKP + Kumawat)
Wednesday	05-11-03	Theory Session Thermodynamics (V Arya)	11:00am – 11:30am	Theory electro- Magnetic Induction (Shashi Prabha)	01:00 pm – 02:00 pm	Physics Practical (Shashi Prabha + HCJ)	3:30pm – 4:00pm	Computer Lab (SKP + Kumawat)
Thursday	06-10-03	Theory Electricity & Magnetism Misconceptions (SKP)	11:00am – 11:30am	Theory Electromagnetic waves /AC (Shashi Prabha)	01:00 pm – 02:00 pm	Physics Practical (Shashi Prabha + KCS)	3:30pm – 4:00pm	Computer Lab (SKP + Kumawat)
Friday	07-11-03	Theory Communication + AMFM (SKP)	11:00am – 11:30am	Theory Logic gate/optical communication. (KCS)	01:00 pm – 02:00 pm	Computer Practical (SKP + Kumawat)	3:30pm – 4:00pm	Valedictory TA + DA

Faculty Members:- ABS - Prof. A.B. Saxena
HCJ - Prof. H.C. Jain
KCS - Dr. K.C. Sharma
SKP - Dr. S.K. Paradkar
VPA - Sh. V.P. Arya
SVS - Dr. S.V. Sharma
Dr. Shashi Prabha
Mr. B.C. Kumawat

Total 18 Sessions

09 Session Theory

09 Session Practical (5 Physics + 4 Computer)

**Training programme for Teaching of Hard spots in Higher Secondary physics to Teachers of Jammu and Kashmir and Haryana
(3rd to 7th NOV, 2003)**

Venue:- Regional Institute of Education, Ajmer (Raj.)

S No	NAME OF PARTICIPANTS	ADDRESS	PHONE No. (OFF)	PHONE No. (RES.)
1	ARUNESH KUMAR	S/o SH. MADAN MOHAN LAR, R/o W.No. 14, H.No. 54, SALAIN TALAB, UDHAMPUR - (J&K) 182101 OFFICE :- GOVT H.S.S UDHAMPUR.		01992273425
2	TARSAIM RAJ SR. LECT IN PHYSICS	VILL PHINDER, P.O. KHOUR DEWANJA TECH. R.S. PURA, DISTT. JAMMU - 18114 (J & K)		01923236454
3	NARESH KUMAR TOMAR LECT IN PHYSICS	GOVT SR. SEC SCHOOL CH. DADRI (BHIWANI) RES.:- H.No. 1443, BACK SIDE ROSE GARDEN, CHARKHI DADRI DISTT. BHIWANI (HARYANA)		01250223821 01258222833
4	AJEET SINGH	VPO- BUDIN, TECH & DISTT. MAHENDERGARH, HARYANA - 123029		9416050190
5	ASHISH AGGARWAL	1540, SHIV SHANKAR COLONY, JAGADHRI, - 135003 PERMANENT: V/P.O RAIPUR RANI, DISTT. PANCHKULA	01734257345	9416181308
6	SURESH KUMAR SINGLA	SINGLA NIWAS, ADARSH NAGAR, NARWANA (JIND)- HARYANA		01684243749
7	DEEPAK ANIK	V & PO. KURAR, SONEPAT, HARYANA - 131039		09896218528
8	NARINDER PAL SINGH	PLOT No. 30, SHOPPING CENTRE, BAKASHI - NAGAR, JAMMU-180001	2663776	0191-2582736
9	SURENDER KUMAR	PHYSICS LECT GGCM SS SCHOOL, 13-P GREEN PARK, PANIPAT		01960-230403
10	RAVINDER SINGH	WARD No. 3, H.No. 19, NOWSHARE, DISTT. RAJORI J&K 185151		
11	GURBACHAN LAL Sr. LECT IN PHYSICS	R/o HARINAGAR, OLD JANIPUR, JAMMU	2533021	
12	K.C. KHAIJURIA LECT IN PHYSICS	R/o 272-A, LANE No. 2, HAROORI BAGH ROAD BOHRI JAMMU		2552731
13	SUDESH KUMAR GUPTA	H.No. 204, KRISHANA NAGAR, DOGRA MOHALLA, JAMMU (J&K)		01912560810
14	SARDUL SINGH	PREET NAGAR (NEAR GURUDWARA), DIGIANA; P.O: GANGYAL JAMMU (J&K)		
15	MAHABIR SINGH	H.No. 1492 SECTOR - 7 KURUKSHETRA, H.No. 97 SECTOR 15-A HISAR		01662-243739
16	BRMAL RAI	9, PHASE - II, HOUSING COLONY, UDHAMPUR		01992-274518
17	ANIL KUMAR LECT IN PHYSICS	PANA CHUYAN, REHMANI GANJ, V&P.O: BERI (JIR) - HARYANA		
18	VIJAY KUMAR	G.S.S.S KOSLI		9416130939

Programme Co-ordinator, Dr. S.K. Paradkar, Reader in Physics, R.I.E. Ajmer. Phone 0145- 2643720 (off), 0145-2641727 (R) 9414007818 (Mob.)